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Generativity is a Core Value of the ESJ:
A Decade of Growth

Erik Erikson (1902-1994) was one of the great psychologists of the 20th century[1]. He explored the nature of personal human identity. Originally named Erik Homberger after his adoptive father, Dr. Theodore Homberger, he re-imagined his identity and re-named himself Erik Erikson (literally Erik son of Erik). Ironically, he rejected his adoptive father's wish to become a physician, never obtained a college degree, pursued independent studies under Anna Freud, and then taught at Harvard Medical School after emigrating from Germany to the United States. Erickson visualized human psychosocial development as eight successive life-cycle challenges. Each challenge was framed as a struggle between two outcomes, one desirable and one undesirable. The first two early development challenges were 'trust' versus 'mistrust' followed by 'autonomy' versus 'shame.' Importantly, he held that we face the challenge of **generativity** versus **stagnation in middle life**. This challenge concerns the desire to give back to society and leave a mark on the world. It is about the transition from acquiring and accumulating to providing and mentoring.

Founded in 2010, the European Scientific Journal is just reaching young adulthood. Nonetheless, **generativity** is one of our core values. As a Journal, we reject stagnation and continue to evolve to meet the needs of our contributors, our reviewers, and the academic community. We seek to innovate to meet the challenges of open-access academic publishing. For us,

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[1] Hopkins, J. R. (1995). Erik Homburger Erikson (1902–1994). *American Psychologist*, 50(9), 796-797. doi:http://dx.doi.org/10.1037/0003-066X.50.9.796

generativity has a special meaning. We acknowledge an obligation to give back to the academic community, which has supported us over the past decade and made our initial growth possible. As part of our commitment to generativity, we are re-doubling our efforts in several key areas. First, we are committed to keeping our article processing fees as low as possible to make the ESJ affordable to scholars from all countries. Second, we remain committed to fair and agile peer review and are making further changes to shorten the time between submission and publication of worthy contributions. Third, we are looking actively at ways to eliminate the article processing charges for scholars coming from low GDP countries through a system of subsidies. Fourth, we are examining ways to create and strengthen partnerships with various academic institutions that will mutually benefit those institutions and the ESJ. Finally, through our commitment to publishing excellence, we reaffirm our membership in an open-access academic publishing community that actively contributes to the vitality of scholarship worldwide.

Sincerely,

Daniel B. Hier, MD

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Dynamic Evolution of Electric Vehicle Trade Network between China and Europe

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Abstract

        China and Europe have promoted the development of electric vehicles to reduce carbon emissions and cope with climate change. In recent years, the sales share of Chinese electric vehicle brands in the European market has increased rapidly. Europe has become the largest export market for Chinese electric vehicles. However, the European Union implemented various temporary tariffs on Chinese electric vehicle brands in 2024, which posed a major challenge to the development of electric vehicle trade between China and Europe. The paper conducts a systematic examination of overall structural characteristics, node centrality metrics, core-periphery architecture and community detection of electric vehicle trade network between China and Europe from 2018 to 2022 by using social network analysis. The results indicate a general upward trend in tighter trade groups and increased connectivity efficiency within the network, while the network density and reciprocity display some fluctuations during this period. From a structural perspective, countries holding central positions in both centrality measures and core-periphery indicators show statistically significant convergence patterns in electric vehicle trade network between China and Europe. Moreover, there has formed different communities and undergone significant composition changes in electric vehicle trade network after 2020, highlighting the strengthening of connectivity within the trade network. This study has both

theoretical and practical implications. It highlights the dynamic changes in electric vehicle trade network between China and Europe, and providing practical implications for Chinese policymakers and Chinese electric vehicle manufacturers through strategic frameworks to enhance bilateral cooperation, market adaptability, and sustainable trade reciprocity with European countries.

Keywords: Dynamic evolution, electric vehicle, trade network, China, Europe

Introduction

It is widely acknowledged that climate change is one of the serious challenges to realize global sustainable development, and countries have increasingly felt economic losses and other serious consequences caused by climate change (Jiang et al., 2021). At the 2015 United Nations Climate Change Conference (COP 21), more than 190 participating countries signed the Paris Agreement on climate change mitigation, agreeing to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees (Voituriez et al., 2019; Yu et al., 2021). The transportation industry has created huge carbon emissions and become a key area of carbon reduction concern for major countries around the world. In 2023, the transport sector generated 8.24 billion tons of carbon emissions, accounting for 23.5% of global carbon emissions (Energy Institute, 2024). Transport carbon emissions are mainly from vehicles, ships and aircraft transport, of which vehicle emissions account for 75% of transport carbon emissions (Hannah, 2020). The global trend of de-carbonization and sustainability has prompted governments and automotive manufacturers worldwide to reduce their carbon footprint. Consequently, electric vehicle (EV) emerges as a viable and attractive solution to reduce carbon emissions and cope with climate change (Hu and Pan, 2023). More and more countries have issued policy initiatives to encourage the adoption of EVs.

China has actively promoted the development and application of EV to cope with the challenges of energy security and environmental protection. As early as 2001, the Chinese Ministry of Science and Technology established the "Three Verticals and Three Horizontals" research and development framework for new energy vehicles. The 11th Five-Year Plan (2006-2010) was a critical phase in transition of China's EV sector to early-stage industrialization, and the 12th Five-Year plan (2011-2015) identified the new energy vehicles as one of the seven strategic industries. China's 14th Five-Year Plan issued in 2021 explicitly identified the development of EV sector as one of the key priority strategy industry. The Chinese government has implemented a series of policies and regulations to support the production and purchase of EVs, including R&D subsidies, dual-credit policy, purchase subsidies, and charging facility construction (Yao et al., 2024). Due to a

national strategy that prioritizes the development of EV sector, China has been the world's largest and fastest-growing producer of EVs since 2015, and has formed industrial chain integration advantages in battery technology and EV manufacturing. In 2023, the number of Chinese EV registrations reached 8.1 million, accounting for 60% of the global EV market (IEA, 2024). To achieve climate neutrality goal by 2050 and green transition, Europe is committed to becoming a global leader in clean, competitive and connected transport. The European Commission and European Parliament have introduced a series of strategies and regulations, including "A European strategy for low-emission mobility" in 2016, "Europe on the move" in 2017, "Europe on the Move: Commission completes its agenda for safe, clean and connected mobility" in 2018, "Sustainable and Intelligent Transport Strategy" in 2020, and "The 2035 ban on the sale of internal-combustion vehicles" in 2023, to promote R&D, market and infrastructure development, and international cooperation of the EV sector. In Europe, the number of EV registrations reached nearly 3.2 million in 2023, with an increase of almost 20% compared to 2022. Europe became the second-largest EV market in the world, accounting for the 25% of the global EV sales in 2023 (IEA, 2024).

In recent years, the sales share of Chinese brands in the global EV market has increased rapidly, from just 4% of global EV exports in 2020 to 21% in 2022 (Boullenois et al., 2023). As for the EV trade between China and Europe, European exports of EVs to China have fallen slightly since 2018, while European imports of EVs from China has accelerated. The market share of Chinese EV brands in the European EV market grew from less than 0.5% in 2018 to 8% in 2023, and Europe became China's largest export market for EVs (Van Wieringen, 2024). China exported over 500,000 EVs to Europe in 2023, accounting for nearly 40% of its total EV exports. According to the European Commission's forecast, this value will further leap to 15% by 2025. The European Commission announced the initiation of EU anti-subsidy investigations into Chinese EV supply chains in October 2023. The Commission concluded in June 2024 that Chinese-made EVs benefited from unfair subsidies and implemented various provisional tariffs in response, ranging from 17.4% to 38.1% (European Commission, 2024). In October 2024, the Commission received the necessary support from Member States to impose definitive duties on Chinese EVs. Through the strategic deployment of import duties and anti-subsidy inquiries, European markets present significant challenges to Chinese EV manufacturers, particularly disrupting their export strategies and market penetration efforts. EV industry embodies the dual strategic value in energy security and climate governance, serving not only as a systematic solution for dismantling the constraints of traditional fossil fuels, but as the key driving force for reconstructing the global low-carbon economy. As nations promote the development of the EV sector,

greater emphasis must be placed on collaboration and equitable competition to prevent protectionist policies from undermining the industry's progress. As key players in the global EV industry, the collaboration between China and Europe is critical for the sustainable development of the EV market. Based on the social network analysis (SNA), this paper analyzes the evolution characteristics of the EV trade network between China and Europe. The results will provide references for China to adjust its EV trade strategy and optimize its EV cooperation with Europe.

Literature Review
Factors affecting EV trade between China and Europe

Researchers mainly examine the factors affecting EV trade between China and Europe from the perspectives of trade status, subsidy policy, supply chain, and trade policy. The EV trade between China and Europe has grown rapidly in recent years, driven by Europe's green transition and China's manufacturing prowess (IEA, 2024). Boullenois et al. (2023) and van Wieringen (2024) provided an analytical overview of EV trade development between China and Europe during the period of 2019- 2023. In March 2023, the European Commission set out targets for reducing emissions from automobiles as part of its "Fit for 55" plan(Busch et al., 2024). To achieve these goals, the sales of EVs in the European Union (EU) should account for approximately 65% of the total new car sales by 2030, and all new car sales should be all-electric by 2035 (Wingender et al., 2024).

The favorable subsidy policies have been the main driving forces of EV trade between China and Europe. European countries have introduced different levels of tax benefits and purchase incentives for EVs since 2020 (ACEA, 2023). Ingeborgrud et al. (2019), and Santos and Davies (2020) revealed that incentive programs and subsidy policies implemented by European countries significantly promote the adoption of EVs. Munzel et al. (2019) examined the impact of monetary and non-monetary policy interventions across 32 European countries on EV market sales by using panel regression analysis. Their longitudinal study demonstrated that energy price dynamics and fiscal incentives, such as direct subsidies or tax reductions, exerted statistically significant positive effects on EV adoption rates. The European EV market has increased rapidly due to the expanding incentive policies of the EU member states. This provided a good opportunity for Chinese EV brands to enter the European market. However, the phase-out of subsidy policy poses challenges for EV trade between China and Europe. For example, Germany cancelled EV purchase subsidies at the end of 2023, resulting in a 27.4% decline in German EV sales in 2024 (IEA, 2024). This had a certain negative impact on Chinese EV brands entering Germany market.

The wave of EVs is propelling a rapid restructuring of the automotive industry's value chain. China has leveraged geographic clustering advantages in critical mineral supply chains and EV infrastructure to achieve economies of scale in manufacturing (Dadush, 2024). Complemented by labor cost advantages and breakthroughs in battery technology and smart manufacturing, China's manufacturing sector continues to enhance its cost management capabilities within the global EV industrial chain. China has developed a strategic multidimensional deployment in building the comprehensive EV industrial chain from mineral raw materials to battery production and final assembly (Duthoit, 2023). This deeply embedded industrial interdependence has essentially positioned China as the foundational infrastructure supporting Europe's green transition (Van Wieringen, 2024).

European trade policy has a significant impact on EV trade development between China and Europe. Through tariffs and anti-subsidy investigations, the EU poses a serious obstacle for Chinese EV manufacturers, particularly in terms of their export activities in the short term (Martyn, 2024). On the other hand, the implementation of tariffs is likely to raise consumer prices for EVs, potentially suppressing market demand within the EU. Excessive dependence on protective tariffs may undermine domestic industries' incentives for technological advancement and efficiency improvements, ultimately weakening their global competitiveness (Andersen, 2023). Therefore, Europe needs to seek a strategic balance between curbing over-reliance and maintaining the development of its own EVs through mechanisms such as mutual recognition of standards under the framework of technological sovereignty and alliances for supply chain resilience in the long run,. Faced with the tariff barriers imposed by the EU, Chinese EV manufacturers need to reassess and adjust their market strategies and reconsider the configuration of their global supply chains (ARC, 2024; IISS, 2024).

SNA approach to analyze EV trade network

Social networks serve as critical frameworks for analyzing intricate, interdependent systems that shape human behavioral patterns and social dynamics across diverse domains (Scott, 2000; Rauch, 2001; Lusher et al., 2013; Jackson et al., 2017). SNA involves mapping and measuring the relationships and interactions that exist among individuals, organizations, or systems. Within a social network, nodes symbolize people or entities, whereas edges (or connections) represent relationships, interactions, or connections between them (Newman et al., 2006). SNA provides a deeper understanding of structural patterns and functioning of individuals or entities by analyzing the connections and structural characteristics between them and visualizing the structure of the network (Scott, 2011; Yang et al., 2016). In the 1980s, SNA began to be widely used in sociology and statistics. SNA provides a

relational perspective for analyzing trade policy interactions, revealing how inter-state network structures (such as centrality and clustering) shape policy diffusion pathways and negotiation game strategies.

The progression of global economic integration has forged interdependent economic linkages between countries in the world, transforming international commerce into a complex relational matrix. International trade demonstrates the network architecture and interaction patterns, which are consistent with the theoretical structure and methodological tools of network science (Snyder and Kick, 1979; Greif, 1989; Rauch, 2001; Fagiolo et al., 2009). Snyder and Kick (1979) introduced SNA into the study of international trade issues, discussing the dependency of differences in economic growth among countries. Smith and White (1992) divided the participants in the global trade network into different structures, such as core, semi-periphery, and periphery. Since then, SNA has been extensively employed in global and regional trade systems, including energy sectors (An et al., 2014; Du et al., 2016), trade relationships (Kim and Shin, 2002; Garlaschelli, 2005; Song et al., 2018), and automotive industry (Pavlínek, 2021; Cho and Kim, 2023), etc. For example, Kim and Shin (2002) analyzed the international trade network based on international commodity trade data by using SNA. The empirical results revealed the dynamic game between globalization and regionalization, and formed a pattern of regionalization under the framework of globalization. An et al. (2014) examined the structural characteristics and dynamic evolution patterns of global crude oil trade relationships based on SNA. The study showed that the crude oil trade network exhibited a core-periphery structure and a strong dependence on geopolitical factors. Pavlínek (2021) depicted the core structure, semi-peripheral structure, and peripheral structure of the European automotive industry by using SNA.

In recent years, SNA has been used to analyze the trade development in the field of the EV sector, including value chain, technology cooperation network, and trade structure evolution. For example, Shao et al. (2021) analyzed the evolution of the global lithium competition network pattern based on the trade data from 2009 to 2018, and found that the trade network structure of lithium has certain path dependencies with a core-periphery structure. Sun et al. (2018) measured EV-related patents cooperation network in China by using SNA . The results showed that the EV-patents cooperation network has evolved smoothly with a growing network density, stable structure, and more cohesive subgroups. Yao et al. (2024) constructed an industrial network from the perspective of the value chain and employed the SNA to study the characteristics, evolution and formation mechanisms of different value chain networks in the Belt and Road regions. Even though SNA has been widely

used, few studies have applied it to the EV trade network between China and Europe.

In summary, current research has examined the various factors influencing the trade of EV trade between China and Europe. However, these studies are largely confined to analyzing the relationships at the trade or micro-market level. There exists a gap in the literature regarding the dynamic analysis of EV trade between China and Europe from a regional and national perspective. Therefore, this paper provides a more comprehensive reflection on the evolving characteristics of the EV trade network based on the trade links between China and Europe.

Methods

SNA demonstrates strong methodological advantages in studying the EV trade network between China and Europe. SNA maps out these relationships in the form of networks where nodes stand for countries and edges symbolize connections between them. Its core focus on relational structures and dynamic interdependencies aligns precisely with the multi-level interactions among China and European countries. In the paper, China and European countries are nodes, and the EV import and export relationships are edges, thus forming a topological network. The paper conducts a systematic examination of trade network overall structural characteristics, node centrality metrics, core-periphery architecture and community detection by using SNA. As a specialized software tool designed for SNA, UCINET 6.0 is used to conduct the calculations and analysis of EV trade network between China and Europe in the paper.

Network structure analysis

The complex trade relationships between China and Europe in the EV sector form the trade network, and the overall structure of this network, in turn, influences the development of EV trade. The measurement of EV trade network structure is drawn on the metrics selected in the study of Yao et al. (2024), and covers four indicators, including network density, reciprocity, average path length, and clustering coefficient. Table 1 shows the formula and description of four indicators.

Table 1: The formula and description of four indicators

Indicator	Formula	Indicator description
Network density (ND)	$ND = \dfrac{m}{n \times (n-1)}$	m is the actual associated edge between two actual points, n is the number of nodes.
Reciprocity (RY)	$RY = p/m$	p is bidirectional relationships; m is the total number of relationships m in a directed network.
Average Path Length (AL)	$AL = \dfrac{1}{1/2n(n+1)}\sum\limits_{i \geq j} d_{ij}$	n is the number of nodes, d_{ij} is the shortest path from node i to node j.
Clustering coefficient (CC)	$CC = \dfrac{2T_i}{k_i(k_i - 1)}$	T_i is the actual number of edges between nodes connected to node i, k_i is the degree of node i.

Network density is used to measure the overall closeness of nodes in the EV trade network. The higher the density value, the closer the overall trade connections are. Reciprocity is the indicator of mutuality and reciprocal exchange, the average path length refers to the average of the shortest path lengths between any two nodes in the EV trade network. The clustering coefficient is a measure of the degree to which nodes in the EV trade network cluster together.

Network node centrality

Centrality is used to measure the importance of nodes in a network in terms of connectivity, identifying nodes that have a critical impact or relevance on the network (Shen et al., 2024). Centrality metrics primarily include degree centrality, closeness centrality, and betweenness centrality. These three centrality metrics possess distinct characteristics and can be employed to shed light on the differential roles and functions of nodes within a network.

Degree centrality measures the number of direct nodes connections in the network, and nodes with high degree centrality are hubs or highly connected entities. Degree centrality can be divided into out-degree centrality and in-degree centrality. Closeness centrality quantifies how close a node is to all other nodes in the network via the shortest paths, and is typically measured by out-closeness centrality and in-closeness centrality. Betweenness centrality measures how often a node lies on the shortest path between pairs of other nodes. Table 2 shows the formula and description of the three centrality metrics.

Table 2: The formula and description of three centrality metrics

Indicator	Formula	Indicator description
Out-degree centrality(OD)	$OD = \dfrac{\sum_{j=1,j\neq i}^{n} x_{ij}}{n-1}$	The ratio of the actual trade connection x_{ij} from node i to node j to the theoretical maximum value of $(n-1)$.
In-degree centrality (ID)	$ID = \dfrac{\sum_{j=1;j\neq i}^{n} x_{ji}}{n-1}$	The ratio of the actual trade connection x_{ji} from node j to node i to the theoretical maximum value of $(n-1)$.
Out-closeness centrality(OC)	$OC = \dfrac{1}{(n-1)\sum_{j=1;j\neq i}^{n} d_{ij}}$	The ratio of the shortest path length d_{ij} from node i to node j to the theoretical minimum value of $(n-1)$.
In-closeness centrality(IC)	$IC = \dfrac{1}{(n-1)\sum_{j=1;j\neq i}^{n} d_{ji}}$	The ratio of the shortest path length d_{ji} from node j to node i to the theoretical minimum value of $(n-1)$.
Betweenness centrality(BC)	$BC = \dfrac{2\sum_{j=1;k=1;j\neq k\neq i,j<k}^{n} \dfrac{g_{jk}(i)}{g_{jk}}}{(n-1)(n-2)}$	The ratio of the probability that node i lies on the shortest path between nodes j and k to the theoretical maximum value.

Community detection

Community detection refers to the identification of a set of nodes that are internally closely connected and relatively distant from other parts in network analysis. These sets of nodes are called communities. Modularity is an indicator used to characterize the community structure of the network. A higher modularity value indicates a clearer community division within the network and a better fit. The mathematical expression of modularity is:

$$Q = \frac{1}{2m}\sum_{i,j}\left(A_{ij} - \frac{k_i k_j}{2m}\right)\delta(c_i, c_j)$$

Here, A_{ij} is the adjacency matrix of the network, k_i and k_j are the degrees of node i and node j respectively, m is the total number of all edges in the network, c_i and c_j are the communities to which node i and node j belong respectively. $\delta(c_i, c_j)$ is an indicator function, when $c_i = c_j$, its value is 1; otherwise, it is 0.

Analysis of EV trade network between China and Europe
Data sources

This study examines the trade dynamics in the EV sector, focusing on China, the United Kingdom (UK), and the EU member states with a time span of 2018-2022. The research scope encompasses two core product categories: pure electric buses (HS2017 code 870240) and other electric road vehicles (HS2017 code 870380). Trade data was collected from the United Nations Comtrade Database (UN Comtrade), with a focus on bilateral trade flow statistics between the selected economies during the period of 2018-2022.

Network structure results of EV trade between China and Europe

      The network structure of EV trade between China and Europe included in the paper are ND, RY, AL, and CC. Table 3 shows the empirical results of EV trade network structure between China and Europe. Firstly, the network density of EV trade between China and Europe showed an overall upward trend from 2018 to 2021, reaching its peak at 0.130 in 2021. There was a slight decline in 2022, which suggested potential supply chain disruption in EV trade possibly due to Russia-Ukraine conflict. The relatively low value of network density indicates that the overall connection is sparse and there is still a large space for development. Reciprocity of EV trade network reached a peak of 0.309 in 2020 with an increase of 58.2% compared to 2018, highlighting the enhanced complementarity between Chinese and Europe. Despite a pullback to 0.247 in 2021, the rebound to 0.277 in 2022 indicated a resilient foundation in EV trade dependency.

      The average path length decreased from 1.845 in 2018 to the lowest point of 1.637 in 2021, reflecting the reduction of supply chain tiers and the increased direct connectivity between nodes. Despite a slight increase to 1.672 in 2022, this indicator was still 8.1% lower than in 2018. The decreasing trend indicates that trade connections have become more direct over time, with fewer intermediary links. The clustering coefficient showed a steady increase from 2018 to 2022, reaching its highest value of 0.749 in 2022. The increasing clustering coefficient suggests a higher degree of local connectivity and more concentrated trade activities. This trend is indicative of the formation of tighter trade groups, which can enhance the overall network's resilience and efficiency.

Table 3: The network structure results of EV trade between China and Europe

Indicators	Year				
	2018	2019	2020	2021	2022
ND	0.124	0.112	0.127	0.130	0.119
RY	0.176	0.253	0.309	0.247	0.277
A L	1.820	1.769	1.647	1.637	1.672
CC	0.669	0.683	0.700	0.736	0.749

Network centrality of EV trade between China and Europe

      The network centrality indicators included in the paper are OD, ID, OC, IC, and BC. Table 4 shows the network centrality results of EV trade between China and Europe from 2018 to 2022. Firstly, Germany shows high centrality scores across all metrics, indicating its dominant role in the EV trade network. Germany ranked the first in both the OD and ID indicators during the period of 2020-2022, indicating its strong export and import activities. The country maintained the highest value of OC from 2018–2022, reflecting core connectivity as an exporter. The country's centrality scores generally increased in IC over time, reaching its highest IC score of 0.839 in 2022. Moreover, the

country frequently ranked highest in BC indicator, underscoring its role as a critical intermediary in the network. These centrality indicators suggest Germany's growing importance as both a producer and a consumer hub in the EV trade network.

Table 4: The centrality of EV trade network between China and Europe

Year	Country	OD	Country	ID	Country	OC	Country	IC	Country	BC
2018	NLD	0.137	DEU	0.114	DEU	1	DEU	0.667	DEU	0.1
	FRA	0.114	GBR	0.083	NLD	1	NLD	0.65	NLD	0.067
	DEU	0.107	NLD	0.080	FRA	0.929	ITA	0.634	POL	0.061
	AUT	0.063	BEL	0.043	AUT	0.867	ESP	0.634	LTU	0.048
	BEL	0.041	FRA	0.042	CHN	0.867	POL	0.634	CHN	0.044
2019	BEL	0.061	DEU	0.055	BEL	1	POL	0.703	DEU	0.069
	DEU	0.037	NLD	0.032	CHN	1	DEU	0.684	GBR	0.054
	FRA	0.022	GBR	0.026	DEU	1	ESP	0.667	BEL	0.047
	NLD	0.020	BEL	0.013	FRA	1	BEL	0.634	ESP	0.048
	GBR	0.020	FRA	0.012	NLD	1	NLD	0.634	CHN	0.044
2020	DEU	0.119	DEU	0.108	DEU	1	DEU	0.788	DEU	0.084
	BEL	0.071	GBR	0.073	FRA	1	NLD	0.722	BEL	0.044
	SVK	0.048	NLD	0.065	GBR	1	BEL	0.703	NLD	0.038
	FRA	0.041	FRA	0.045	NLD	1	POL	0.703	FRA	0.033
	CHN	0.032	BEL	0.026	AUT	0.963	FRA	0.684	GBR	0.032
2021	DEU	0.137	DEU	0.118	AUT	1	DEU	0.788	GBR	0.058
	CHN	0.099	GBR	0.089	BEL	1	BEL	0.722	DEU	0.056
	BEL	0.061	BEL	0.054	CHN	1	NLD	0.722	BEL	0.026
	SVK	0.038	FRA	0.050	DEU	1	DNK	0.722	NLD	0.022
	CZE	0.021	NLD	0.034	ESP	1	GBR	0.703	DNK	0.022
2022	DEU	0.135	GBR	0.081	BEL	1	DEU	0.839	GBR	0.066
	CHN	0.119	DEU	0.072	DEU	1	NLD	0.813	DEU	0.053
	BEL	0.038	BEL	0.059	ESP	1	DNK	0.813	NLD	0.037
	ESP	0.034	FRA	0.043	FRA	1	BEL	0.788	DNK	0.023
	FRA	0.021	NLD	0.034	GBR	1	HUN	0.788	BEL	0.023

Note: The country name uses the ISO 3166-1 alpha-3 code

Secondly, both Belgium and the Netherlands are strategic hubs in the EV trade network. Belgium maintained a relatively high centrality across all metrics throughout the period, with notable scores in OD, OC and IC. Especially, Belgium emerged as a key intermediary and achieved a significant increase in the IC indicator over the time, indicating critical export connectivity. However, the score of indicator BC appeared to decline slightly over time. The Netherlands had a high OD ranking in 2018 and 2019, and high value of ID over time. The country also had consistently strong IC score, emphasizing its role as a trade gateway. However, the country's centrality scores in OD and BC declined during the period of 2018-2021, suggesting a reduced role in the EV trade network.

Thirdly, both UK and France are key players in the EV trade network. France has a consistent presence in the network with moderate centrality

scores in OD and ID. Its centrality scores of OC fluctuated slightly but remained significant from 2018 to 2022, indicating a stable role as both a producer and consumer of EVs. The UK had significant centrality scores in BC and ID from 2018 to 2022. UK ranked first in both BC and ID indicators in 2022, suggesting growing import reliance and an intermediary role.

Finally, China's EV exports to the European market demonstrate robust growth, reflecting increasing market interdependence. China's OD ranking rose from the 5th to the 2nd from 2018 to 2022, signaling growing export activity. The country achieved the highest OC scores from 2019 to 2021, suggesting enhanced export network efficiency. In 2022, China had a BC score of 0.053 and an OC score of 0.813, indicating its growing role in the EV trade network. The rising centrality scores suggest that China is becoming a more important player in the trade network, due to its expanding EV production and exports to Europe. Other countries like Austria, Poland, and the Czech Republic had higher centrality scores and played important roles in the EV trade network from 2018 to 2022, particularly in terms of OC and IC indicators.

Network core-periphery structure of EV trade between China and Europe

The paper uses the Core-Periphery algorithm in UCINET 6.0 to conduct a quantitative analysis of the core-periphery structure for the EV trade network between China and Europe. The criteria for identifying core country in the trade network are set as having a coreness value greater than 0.1. Country with a coreness value between 0.05-0.1 is classified as the semi-peripheral country, and all other nodes with a coreness value less than 0.05 are considered to be in the peripheral countries. Table 5 shows the network core countries of EV trade between China and Europe from 2018 to 2022.

Table 5: Network core countries of EV trade between China and Europe

Year	Core country
2018	DEU (0.476), NLD (0.457), AUT (0.420), FRA (0.353), ESP (0.251), GBR (0.237), BEL (0.206), SVK(0.144), POL (0.139), HUN (0.120).
2019	DEU (0.425), NLD (0.398), BEL (0.377), FRA (0.367), AUT (0.366), ESP (0.300), GBR (0.291), SWE (0.129), ITA (0.124).
2020	DEU (0.445), NLD (0.376), FRA (0.372), GBR (0.369), BEL (0.346), ESP (0.317), ITA (0.236), AUT (0.209), CHN (0.162), SWE (0.121).
2021	DEU (0.494), FRA (0.382), BEL (0.346), GBR (0.324), ESP (0.316), ITA (0.307), NLD (0.212), AUT (0.208), CHN (0.203), SWE (0.152).
2022	DEU (0.509), FRA (0.398), BEL (0.356), ESP (0.331), GBR (0.314), ITA (0.286), CHN (0.245), NLD (0.202), SWE (0.133).

Note: The country name uses the ISO 3166-1 alpha-3 code

According to the Table 5, Germany consistently remained the most central country in the EV trade network throughout the period, with its centrality score increasing from 0.476 in 2018 to 0.509 in 2022. This indicates

Germany's dominant position and growing importance as a core hub in the EV trade network between China and Europe. This advantage stems from the country's strong automotive manufacturing industry, technological leadership in sustainable mobility solutions, and comprehensive international trade facilities.

Secondly, Belgium, France, UK, and the Netherlands were consistently among the core countries, maintaining relatively high centrality scores across the period of 2018-2022. Among the four countries, France maintained a consistently high and stable centrality score, especially ranking second in 2021 and 2022. This underscores France's important role in the EV trade network, driven by its automotive industry and government support for EV adoption and production. Belgium maintained prominent positions throughout the period of 2019-2022, and ranked third in 2021 and 2022 respectively. The UK's centrality score fluctuated but remained significant, particularly in 2020 and 2021. The Netherlands showed a notable decline in centrality from 0.457 in 2018 to 0.212 in 2021, with slight recovery to 0.212 in 2022. This indicates a potential reduction in its role as a core intermediary in the network.

Thirdly, China's rising centrality scores, especially as it moved to the forefront of the trade network in 2021 and 2022, signal its increasing prominence in the EV trade network. This changing role of China is mainly attributed to its expanding EV exports to Europe and increasing technological capabilities in the EV sector. Austria, Spain, Italy, and Sweden also maintained high centrality scores, indicating their important roles in the EV trade network. These countries contribute to the network through their automotive industries, trade infrastructure, and strategic locations.

Community detection of EV trade between China and Europe

This paper uses the community detection module in UCINET 6.0 to analyze the trade networks of EVs in China and various European countries. The networks from 2018 to 2020 exhibited low modularity (0.177, 0.15, and 0.18 respectively), making them difficult to divide into distinct communities. The modularity in 2021 and 2022 was 0.28 and 0.23, respectively. The community detection results of EV trade between China and Europe are shown in figure 1 (the same community is represented by the same color, and the countries with missing data are not included).

Figure 1: Networks community of EV trade between China and Europe

2021   2022
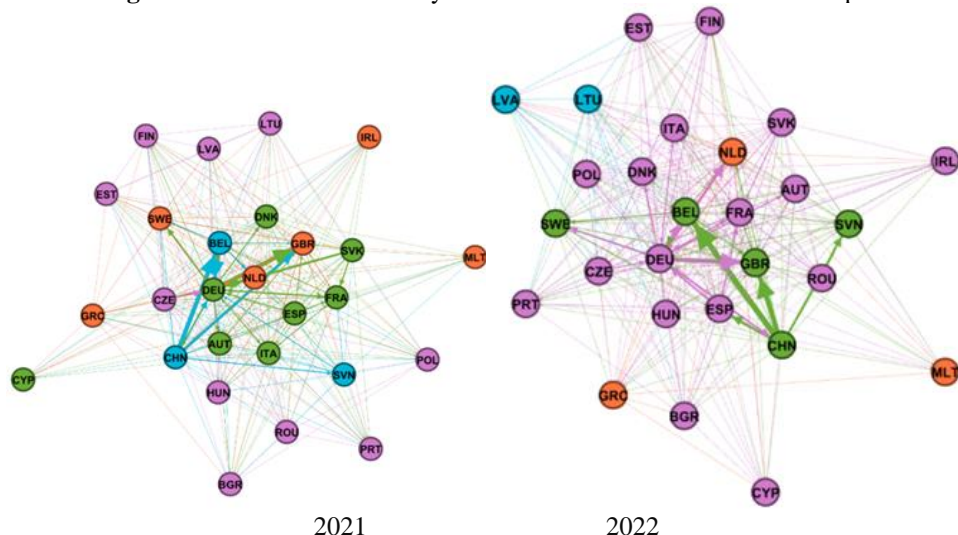
Note: The country name uses the ISO 3166-1 alpha-3 code

It can be seen from the Figure 1 that divisions of different communities are closely related to the development level of each country in the field of EVs and the relevant geographical locations. In 2021, the EV trade networks between China and European countries were divided into four groups. The largest cluster (depicted in pink) consisted of Poland, Portugal, Romania, Bulgaria, Hungary, the Czech Republic, Finland, Latvia, Lithuania, and Estonia. These countries are mainly situated in Eastern Europe and represent those that have demonstrated limited investments and possess underdeveloped technological capabilities in the field of EVs. The second-largest group, represented by green, included Cyprus, Denmark, Germany, Austria, Italy, Spain, France, and Slovakia. These countries are mainly located in Western Europe, covering those that have made significant investments and high technological levels in the field of EV sector. The third cluster was indicated in orange, covered Greece, Sweden, the Netherlands, and the UK. Finally, the smallest group was formed by China, Belgium, and Slovenia, indicating that China's main reliance path for EV exports to Europe

In 2022, there was a significant change in the community composition of this trade network. The largest community expanded its membership from 10 countries in 2021 to 16 countries by 2022, spanning Western, Central, and Eastern Europe. This community is spearheaded major European automobile countries, such as Germany, France, and Italy. The second community was composed of China, Belgium, the UK, Slovenia and Sweden, indicating the deepening of strategic interaction between China and Europe in the EV trade. The remaining countries occupied relatively peripheral positions within the trade network.

Discussion

The paper constructs a China and Europe EV trade network and conducts a systematic examination of overall structural characteristics, node centrality metrics, core-periphery architecture and community detection by using SNA.

The overall structure of China and Europe trade network in the field of EV sector is undergoing continuous dynamic changes. Although the network density and reciprocity fluctuated, there was an obvious trend of tighter trade groups and improving connectivity efficiency. The dynamic changes of EV trade network are driven by combinations of the policy and regulatory environment, market demand, geopolitical and economic factors, and the value chain. China is the world's largest and fastest-growing producer, consumer and battery producer of EVs, and has formed an industrial chain integration advantage in battery technology and EV manufacturing. European countries have provided support measures such as purchase subsidies, tax incentives, and the construction of charging networks, which have promoted the popularity of EVs. Especially, the European Commission launched the "Sustainable and Intelligent Transport Strategy" in 2020, which aimed to have at least 30 million zero-emission cars on European roads by 2030 (European Commission, 2021). The increasing market demand has provided a broad market space for Chinese brands EV to enter European countries.

In the context of EV trade between China and Europe, countries that exhibit a high degree of centrality and coreness in the network tend to overlap significantly. The EV trade forms a core-periphery network structure, with Germany, Belgium and other major European automobile countries as the center countries. Firstly, Germany has a dominant position in the EV trade network, which is matched by the country's share of the European market. According to the IEA (2023), Germany is the largest EV market in Europe with 830,000 EVs sold in 2022. The country also serves as the headquarters for globally renowned automotive manufacturers such as Volkswagen and Mercedes-Benz Group. Secondly, France, Belgium, UK, and the Netherlands are countries with developed automotive industries, and their manufacturing advantages and larger market space have become the basis for the core countries of EV trade network between China and Europe. Moreover, Belgium and the Netherlands maintain significant positions in EV trade network due to their advantageous geographic positioning and developed transport system. Thirdly, the geographical redistribution of core countries within the EV trade network demonstrates significant structural realignment during the period of 2018-2022. For example, the Netherlands experienced a progressive decline in network centrality, ultimately falling outside the top five influential nodes in 2022. China has experienced the dynamic change from a semi-marginal country to a core country. China's share in the EV trade network has increased

rapidly since 2020 and became the core country in the trade network by the end of 2022.

The community detection of EV trade between China and Europe indicates that distinct communities emerged after 2020, with substantial shifts in the composition of each group over time, highlighting the evolving nature of inter-country associations and their dynamic realignment. In major automotive industrial countries of Europe, the demand for EVs has been continuously increasing with the support of policies for the development of EVs, the advancement of EV technology and the improvement of consumers' environmental awareness. The status of these countries in the community has become more important due to the expansion of market demand. For example, as the largest automotive market in Europe, Germany's increased acceptance and demand for EVs have enhanced its influence in the trade community. Moreover, the continuous deepening of trade cooperation between China and European countries has prompted some European countries to establish closer ties with China in the EV trade community. The share of Chinese EV brands in the European market has gradually expanded since 2020, promoting the adjustment of the trade communities between China and Europe.

This research acknowledges several limitations that should be addressed in subsequent studies. Future investigations should prioritize incorporating more updated data to enhance the precision and dependability of the China and Europe EV network analysis. A second limitation lies in the absence of a comprehensive examination of mechanisms behind EV trade network within the China and Europe, especially the impact of the Russia-Ukraine conflict on the supply chain of China and Europe EV trade. Thirdly, there is a critical need to integrate predictive analysis into future research frameworks, employing scenario-based modeling or machine learning approaches to forecast EV trade patterns and market evolution between China and Europe under varying geopolitical and economic conditions. These gaps necessitates targeted investigation in future research to shed light on the underlying mechanisms shaping cross-regional EV market interactions.

Conclusions

EV as a strategic emerging industry has become an important measure to achieve green and sustainable development. Based on the SNA, the paper analyzes the dynamic evolution characteristics of EV trade network between China and Europe from 2018 to 2022. Empirical findings demonstrate an overall upward trend in tighter trade groups and increased connectivity efficiency, although network density and reciprocity exhibit certain fluctuations. From a structural analysis perspective of the EV trade network between China and Europe, countries occupying central positions in both core-periphery indicators and centrality metrics demonstrate statistically significant

convergence patterns. Moreover, different communities emerged in the EV trade network between China and Europe after 2020. The composition of each community has undergone substantial changes over time, highlighting the further improvement in the connectivity of EV trade between China and Europe.

From a theoretical perspective, this paper provides a multidimensional assessment of trade patterns, actor influence, and hierarchical dynamics by examining the overall structural characteristics, node centrality indicators, core-periphery structure and community detection of EV trade network between China and Europe. The study finds that the overall structure of the trade network is dynamically evolving, with increasing connectivity efficiency despite fluctuations in network density and reciprocity. This evolution is driven by factors such as policy support, market demand, economic conditions, and the value chain. The rapid development of China as a core country in the trade network, along with the dominant positions of major European automotive countries like Germany and Belgium, highlights the significance of industrial chain integration and geographic advantages. The detection of distinct communities and their dynamic realignment after 2020 underscores the evolving nature of inter-country trade associations in the EV sector. These findings contribute to the broader international trade literature in highlighting the dynamics changes in the EV trade network between China and Europe.

From a managerial perspective, this paper intends to provide actionable insights for decision makers and industry stakeholders in the field of EV sector. Firstly, Chinese government agencies should engage in strategic dialogue with the EU to address subsidy concerns. Simultaneously, they should transparently demonstrate the consistency of China's EV subsidy policies with international trade norms. The Chinese government should highlight the key role of Chinese EVs in accelerating the global shift to sustainable transportation, including emission reduction and technological innovation. The EU and China agreed to consider minimum pricing for Chinese EVs, offering an alternative to current tariffs in April 2024. Joint government efforts could now advance a reciprocal market access protocols and fair competition standards to balance market access and equitable growth. Secondly, Chinese EV manufacturers could explore strategic partnerships with firms in key European markets, such as Germany, France, and Belgium through joint ventures, technology-sharing arrangements, and collaborative R&D programs. By integrating the regulatory expertise and localized supply chains of European strategic partners, Chinese manufacturers, such as BYD and Geely, can mitigate geopolitical risks while accelerating the time-to-market of EV models in specific European countries. This strategy cooperation will transform transaction-based exports into embedded value

chain participation, aligning with the EU's strategic autonomy agenda while ensuring China's foothold in the decarbonized mobile ecosystem. These alliances would facilitate smoother market penetration and technology acquisition while mitigating risks through shared responsibilities. Establishing localized production and supply chains in Europe could help circumvent tariff barriers and improve operational responsiveness. For instance, constructing manufacturing facilities in Germany, Belgium, and Central and Eastern European countries like Hungary and Slovakia would enhance supply chain adaptability and regional market responsiveness.

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Data Availability: All data are included in the content of the paper.

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Sectoral Interconnectedness: insights from five sectors in 'smart' urban planning (Energy, Transport, Waste Management, Buildings, and Cities)

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Abstract
'Smart' urban planning has become essential for addressing contemporary urban challenges, with sectoral interconnectedness at its core for achieving sustainable, efficient, and resilient cities. Yet it remains unknown to what extent the elements of smart are interlinked across the sectors. Therefore, this paper examines the degree of interconnectedness across five smart sectors: Energy, Transport, Waste management, Buildings, and Smart cities, covering site to city-wide scale. A mixed-method approach was employed, combining qualitative thematic coding and quantitative correlation analysis using NVivo's suite of cluster analysis tools. Strong interconnectedness was identified between the Energy and Transport sectors, driven by digital transformation and data-driven decision-making. In contrast, weak interconnectedness was observed between transformative cross-sectoral (CS) goals such as climate adaptation and sustainability. Smart Cities was the most interconnected sector, acting as a central platform where CS goals like sustainability, digital transformation, and real-time data utilization converge. Nevertheless, sectoral silos and inconsistent interoperability threaten the realization of holistic smart urban outcomes. This highlights the urgent need

for cohesive frameworks that systematically align CS goals across sectors, ensuring that technological innovations contribute meaningfully to long-term environmental and social objectives. The paper's insights can help policymakers and practitioners strengthen cross-sector collaboration, optimize urban systems, and promote integrated, adaptive, and sustainable smart urban planning.

Keywords: Smart urban planning, Sectoral interconnectedness, Smart energy, Smart transport, Smart waste management, Smart buildings, Smart cities

Introduction
Lack of integration/convergence among smart sectors

The term 'smart' has become a central concept in urban planning, reflecting a shift towards leveraging advanced technologies, data-driven strategies, and innovative practices to enhance urban efficiency, sustainability, and resilience (Anthopoulos, 2015; Russo, 2025). Its application spans various policy and planning sectors, leading to the emergence of 'Smart Infrastructure' (Broo *et al.,* 2022), 'Smart Buildings' (Borhani *et al.,* 2022), 'Smart Traffic' (Eldafrawi *et al.,* 2024), 'Smart Transport' (Haydari & Yilmaz, 2022), 'Smart Mobility' (Babapourdijojin *et al.,* 2024), 'Smart Energy' (Aliero *et al.,* 2022), and 'Smart Urban Governance' (Jiang, 2021). This multi-dimensional perspective integrates technology, people, and institutions, highlighting the role of Information Communication Technologies (ICTs) in shaping the future of cities and urban planning (Alrashed, 2020; Meng & Zhu, 2024). In this context, the interconnectedness of urban challenges, such as energy efficiency, carbon emissions reduction, and building sustainability, is recognized, implying that smart solutions should emphasize holistic approaches (Brčić *et al.,* 2018; Lee *et al.,* 2023). For example, Smart Energy solutions can influence the design and operation of Smart Buildings, while Smart Transport systems depend on city-wide infrastructure underpinned by Smart Governance.

Despite recognizing the concept of interconnectedness as crucial, the problem is that the extant literature predominantly addresses smart applications in isolated sectoral domains, e.g., Smart Transport, Smart Energy, and Smart Waste Management (Onyango *et al.,* 2025), with limited emphasis on their inherent synergistic potential. This sectoral isolation significantly hampers the realization of integrated and efficient urban sustainability, resilience, and innovation, likely diminishing the potential full impact of the concept 'smart'.

Interconnectedness, as conceptualized here, involves explicitly analyzing, aligning, and cross-referencing the smart elements, i.e., meanings, goals, and applications (see Onyango *et al.,* 2025), between two or more smart sectors. However, the lack of a systematic investigation into the

interconnectedness required to facilitate integration among the various smart sectors may be a source of sub-optimality (e.g., ineffectiveness and inefficiency) within urban planning (Onyango *et al.,* 2025; Han & Kim, 2024). This is true, if 'smartness' (in policy and practice) is being pursued within sectoral silos bereft of a carefully considered and calibrated interconnectedness between the smart elements.

Onyango *et al.* (2025) explored whether the term smart was similarly understood and applied in three smart sectors (Energy, Transport, and Waste Management), and found that the goals pursued in each sector were not always the same. But they were steeped in a language of eco-modernism and a technology-based paradigm, which was hollow in meeting any fundamental transformation of the status quo. Furthermore, there were inadequate efforts regarding the coherent application of 'smart' in a manner aimed at achieving an over-arching, converging, or collective goal across the sectors. Therefore, the concept of smart required a shared theoretical foundation applicable across the sectors.

Following the conclusion that smart planning was not always similarly understood and applied in the Energy, Transport, and Waste Management sectors, one wonders what the level of interconnectedness exists across the broader smart planning spectrum. Thus, to what extent do the various sectors of smart planning exhibit interconnectedness via their smart elements? Therefore, this paper aims to uncover how smart elements (i.e., meanings, goals, and applications) are interconnected across five sectors of urban planning. The insight can help policymakers and urban planners to better leverage smart elements towards achieving convergent outcomes within cohesive 'smart' urban planning (Kondiba & Kothalanka, 2023). This can contribute to answering Cavada *et al.* (2016), who asked whether planning could go beyond the pragmatic engineering-based attempt to improve the operation of individual urban infrastructure and/or services through technology, via an underpinning theory of the elements to be connected.

Following the introduction (section one), section two presents the idea of interconnectedness as part of setting out the context for analyzing and interpreting the findings. This is followed by the methodological approach outlining the procedures for data collection and analysis (section three). Subsequently, the results (section four) and discussions (section five) are presented. The study's conclusions and recommendations are drawn up in the final section (section six).

Interconnectedness: purpose, benefits, and challenges

Interconnectedness, as a theoretical framework in this paper, is premised on the acknowledgment that while each sector has its own bespoke application underpinning smart, there is also a need for some collective,

aligned, or convergent big-picture outcome(s) to be delivered by smart. This follows from the concept of convergence (Onyango *et al.,* 2025), which suggests that the integration of sectoral elements within smart urban planning is necessary to achieve coherent and effective urban development. Although Smart Buildings and Smart Transport systems employ different technologies, ultimately, both aim to deliver the convergent goals of reducing carbon emissions and enhancing energy efficiency. Their effectiveness is significantly increased when they are interconnected; within interdependencies that create a broader smart urban ecosystem where energy use, mobility patterns, digital governance, and carbon emission and/or sustainability objectives are coordinated and optimized, through holistic smart urban strategies (Esfandi *et al.,* 2024) and initiatives.

In terms of policy implementation (Hurlimann *et al.,* 2021), interconnectedness becomes crucial for creating a coherent framework that ensures the alignment of the conceptualization, calibration, and delivery of smart urban outcomes (Bruzzone *et al.,* 2021). This matters to the efficiency and effectiveness of urban planning based on a growing awareness that leveraging the synergies among elements (i.e., meanings, goals, and applications) of various smart sectors can be a cost-effective way to address the interrelated nature of urban challenges (Javed *et al.,* 2022, Onyango *et al.,* 2025) as resources are limited.

Interconnectedness can be exemplified within the lens of Sustainable Smart Planning Theory and Cyber-Physical Systems, emphasizing integrated, holistic approaches necessary for transformational smart urban outcomes. Thus, highlighting the seamless integration of physical infrastructure with digital technologies (Andronie *et al.,* 2021), ensuring that technological advancements align with long-term environmental, social, and economic goals (Bruzzone *et al.,* 2021).

Despite the recognition of interconnectedness, sectoral fragmentation continues to hinder cities from fully harnessing the potential of smart urbanism (Cai *et al.,* 2023): as coordinated interconnectedness is often not evidenced. Other studies have identified challenges to interconnectedness, for instance, technological fragmentation hindering the convergence of outcomes as sector-specific tools are often developed in silos without consideration for interoperability (Balica & Cuțitoi, 2022), thus limiting opportunities for CS synergies. Data fragmentation compounds these challenges (Javed *et al.,* 2022). Each sector generates large volumes of data, yet inconsistencies in data formats, privacy concerns, and a lack of interoperable systems can prevent effective data sharing and analysis (Braun *et al.,* 2018). Regulatory and institutional barriers (Venegas *et al.,* 2021) can further exacerbate these challenges, as sector-specific policies frequently operate independently,

creating silos that impede the development of cohesive approaches to smart urban planning.

One way to address the above challenges requires a linkage of rationale and calibration in terms of smart elements (understanding, goals, applications) across sectors, to better coordinate and integrate the concept and practice of smart. For example, the alignment of Smart Energy elements with those of Smart Transport could simultaneously reduce emissions and enhance mobility. Furthermore, Smart Buildings can act as critical nodes within a city's energy network, contributing real-time data on energy use and environmental conditions that inform and underpin urban planning strategies. Smart Waste Management elements can also be integrated into broader Urban Governance elements, supporting decentralized waste processing and promoting the overarching goal of a circular economy.

In practice, realizing interconnectedness will require awareness of the smart elements and their inherent potentialities, when interconnected, among the sectors. The vision is for urban planners and policymakers to be able to build interconnected 'smart' ecosystems that maximize the potential of each smart sector while aligning and integrating sectoral interdependencies, for example, at the elements level (i.e., meanings, goals, and applications).

Methodological Approach

Following a content analysis approach, this paper will employ qualitative analysis via thematic coding and quantitative analysis via correlation analysis within NVivo's cluster analysis function. Data collection to analyze the level of interconnectedness was as described in Onyango *et al.* (2025), but with two differences. One, the three smart sectors (Energy, Transport, and Waste Management), was expanded by adding Smart Buildings and Smart Cities to capture a broader, more practical and systemic view of urban interconnectedness. Two, while the city scale added a broader overarching platform upon which the other sectors and their smart elements interact, the building scale added a narrower scale towards the site level. This expands the scope in Onyango *et al.*'s (2025) to explore a wider dynamic arena that shapes both the opportunities and barriers towards smart outcomes (Han & Kim, 2024). A summary of the methodological steps is provided below.

Step 1. A systematic review of literature supported by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to guide the identification of documents was undertaken. Search criteria encompassing keywords such as "smart energy," "smart transport," "smart waste management," "smart buildings," and "smart cities," were applied. Boolean operations (e.g., "smart AND energy OR transport OR buildings OR cities") were applied in Google Scholar, Scopus, and ScienceDirect to retrieve relevant academic articles, book chapters, and

conference proceedings. The initial search yielded over 150,000 documents. A staged review process was implemented to refine the dataset, consisting of reviewing titles, abstracts, and full texts. Inclusion and exclusion criteria, to ensure that the selected documents meaningfully contributed to the issue, were applied, resulting in the selection of 201 documents that formed the basis for subsequent analysis (Figure 1). Inclusion criteria confined the search to documents that were potentially most appropriate to the search, meeting standards of high-quality, methodological, temporal and sectoral relevance. In contrast, exclusion criteria helped maintain the focus, credibility, and relevance of the dataset by excluding those outside the inclusion criteria. Thus, the study avoided the dilution of analytical rigor and prevented the incorporation of documents that could be irrelevant, introduce bias, or obsolete perspectives.
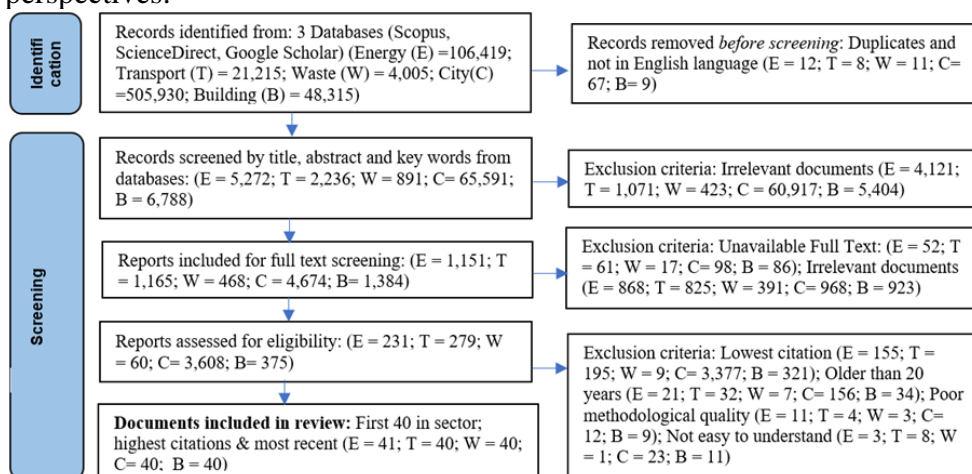
Figure 1. PRISMA ensures that the search for relevant literature to analyze is systematic and transparent (adapted from Page *et al.,* 2020).

Step 2. Each document from Figure 1 was coded line-by-line to ensure consistency and rigor. Data extraction was conducted using NVivo software to facilitate textual analysis based on codes developed to categorize data into three main elements of the term smart (Onyango et al., 2025):

- **Understandings**: Texts describing how smart is defined or understood within each sector (Code M).
- **Goals**: Statements outlining the overarching aims, objectives or priorities of going smart (Code G).
- **Applications**: Descriptions of specific technologies or processes used to operationalize smart concepts (Code D).

Step 3. The codes (M, G and D) were analyzed using various NVivo (V1.5) cluster analysis functions. First, the word cloud function was applied to M

codes to explore key patterns in the texts used. Second, interconnectedness across the sectoral goals and applications (G and D codes) was generated using the Hierarchical Chart option to illustrate the relative prominence of each cross-sectoral (CS) goal, showing the proportional distribution and interconnectedness in the data set. Third, the Coding Comparison Query function was applied to CS goals to show the sectoral distribution (intensity) by goals. Fourth, Circle graphs, based on Pearson correlation coefficient analysis, helped to show how lines of 'connectivity' from one sector were connected to another sector by frequency. Finally, cluster analysis of divergence patterns was generated using a horizontal dendrogram.

Overall, these analyses emphasized the linkages and facilitated an understanding of how smart elements of these sectors are interconnected. The strength of interconnectedness was determined using NVivo's correlation analysis tools, where higher coding co-occurrence via higher Pearson correlation coefficients indicates "strong" connections. Moderate and Weak connections, respectively, were determined by progressively lower correlation values and fewer shared codes across sectors and goals (Table 1).

Table 1. A summary of the strengths of interconnectedness between CS elements based on correlation coefficient data within NVivo software using defined thresholds. See results in Figures 4 – 9.

Connection Strength	Measurement criteria (NVivo Analysis) and our interpretation
Strong (0.70 – 1.00)	High level of interconnection between two sectors (Red line)
Moderate (0.40 – 0.69)	Medium degree of interconnection (Green line)
Weak (0.00 – 0.39)	Limited or minimal interconnection, sectors function mostly in isolation with little thematic overlap (Black line)

Some limitations with our document analyses are worth mentioning (Bowen, 2009). For example, documents may not be complete or written in an objective fashion; it might be difficult to determine which information is precise or unbiased, and documents may have insufficient detail as they are produced for some purpose other than research. A document may also state something very different from all the other documents. Overall, we aimed to mitigate bias and uncertainty by using the same coding where the reference was to the same element of interest. Furthermore, the PRISMA approach helped us systematically identify the relevant documents to analyze. However, repeatability of the work can be restricted as documentation retrievability by another researcher may not reveal a set of documents identical to ours.

Results

Interconnectivity: Convergence in goals and applications

The analysis of the 75 most frequent words (Figure 2) across goals and applications codes (i.e., G and D) reveals significant patterns of convergence in how smart is conceptualized across the five sectors. The centrality of terms

such as 'data', 'systems', and 'energy', followed by 'information, planning, management, transportation, renewables, and traffic', highlights their foundational roles in defining smart urban systems. 'Energy' emerges as a core component, not only as a standalone sector but also as a supporting element for other sectors like Transport and Buildings, underscoring the vital function of energy in enabling integration and operational efficiency across smart systems.

Word	Count
Energy	29693 (27.9%)
Smart	19930 (18.7%)
Buildings, cities	9589 (9.0%)
System, planning	8362 (7.9%)
Information	5380 (5.1%)
Traffic	5295 (5.0%)
Management, optimal	5291 (5.0%)
Renewable	4598 (4.3%)
Model	4509 (4.2%)
Data	4476 (4.2%)
Demand	4347 (4.1%)
Transportation	4336 (4.1%)
Cost	4054 (3.8%)
Sustainability, environment	2764 (2.6%)
Technologies	2748 (2.6%)
Efficiency	1960 (1.8%)
Integration	1838 (1.7%)
Total	119170(100%)

Figure 2. The 75 most frequent words among the sectors focusing on goals and applications.

Terms like 'buildings', 'traffic,' and 'cities' emphasize the importance of infrastructure within smart systems. Buildings play a dual role as significant energy consumers and contributors to broader urban goals. They act as nodes in urban networks, linking energy management, transport, and data-sharing systems.

Technology and data are prominent themes, as evidenced by the frequent mention of terms such as 'model', 'systems', 'information', and 'technology'. This convergence highlights the reliance on advanced tools like the Internet of Things (IoT) and real-time analytics to drive optimization in the sectors. These technologies underpin the ability to achieve energy efficiency, improve traffic flow, and reduce waste. The repeated focus on these tools suggests a shared understanding that technological innovation is central to achieving the objectives of smart urban systems.

The word frequency analysis (Table in Figure 2) reveals a *relatively* strong emphasis on sustainability (2.6%) and 'renewable' (4.3%). The term 'integration' (1.7%) points to a collective effort to interconnect systems and align sector-specific operations with broader urban planning goals. Words such as 'cost', 'demand', 'optimal', and 'time', reflect the financial and logistical barriers to implementing smart systems, thus implying the need for

collaborative CS approaches that leverage technology to overcome these barriers.

Overall, while the sectors may have distinct objectives, the frequent recurrence of certain terms suggests that the sectors share a common understanding of smartness: providing a sense of interconnectedness as a foundation for coordinated action and interoperability in urban planning. Areas where convergence is observed are areas where cohesive frameworks to enhance optimized and seamless integration across interconnected domains can occur.

Interconnectedness: goals and applications

Analyzing the coded data by sector revealed that certain priority themes consistently emerged across them. These recurring themes, with some overlaps, were distilled into five cross-sectoral (CS) goals (Figure 3) and sub-goals in parenthesis:

- o CS1: **Sustainability** (Renewable energy, Environmental conservation, Social equity, Greenhouse gas emissions, Sustainable resource consumption).
- o CS2: **Resource Optimization** (Energy efficiency, Reduce waste generation and promote recycling, Optimize transport networks for minimal environmental impact, Water-saving technologies, Circular economy practices).
- o CS3: **Real-Time Data Utilization** (Predictive analytics for urban planning, IoT for dynamic system monitoring, Integrate real-time traffic, Real-time decision-making, Data-sharing platforms).
- o CS4: **Climate Adaptation** (Infrastructure resilience, Flood and disaster preparedness, Heat-resilient urban designs, Adaptive governance frameworks, Climate risk assessment).
- o CS5: **Digital Transformation** (Smart city technologies (IoT, AI, Big Data), Integrated city dashboards for monitoring, Digital governance and citizen engagement, Platforms for cross-sector data integration, Cybersecurity in urban digital systems).

In Figure 3, the size of the rectangle illustrates the relative prominence of each goal, showing its proportional distribution within the dataset. This is based on NVivo's coding density and co-occurrence analysis, i.e., overall presence and strength of connections rather than absolute frequency counts. Digital Transformation (CS5), followed by Climate Adaptation (CS4), are the most frequently stated goals, while Resource Optimization (CS2) and Sustainability (CS1) appear less frequently. We note the prominence of what can be described as 'operational goals' (i.e., CS2, CS3, CS4, CS5), referring to day-to-day actions that enable processes, e.g., Digital Transformation,

which facilitate automation and connectivity. In contrast, outcome or transformational goals, representing long-term overarching targets of fundamental game-changing outcomes, i.e., CS1 and CS4, are less prominent.
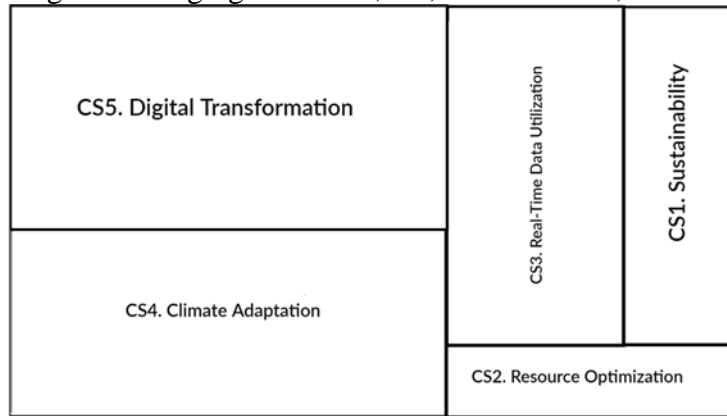
Figure 3. CS goals among the five sectors were generated using the Hierarchical Chart option in NVivo.

To further analyse interconnectedness, the percentage contribution of the five CS goals, by sector (sectoral intensity by goal), was generated using NVivo's Coding Comparison Query function. The values were derived by comparing coding references across different sectors and goals, i.e., specifying CS goals (CS1 to CS5) as nodes and defining sources (codes G and D) (Table 2).

Table 2. How do different sectors contribute to the CS goals? The two highest percentage contributing sectors for each goal are in red.

Smart sectors	CS1	CS2	CS3	CS4	CS5	Total	Average
Cities	**35**	20	**25**	**30**	**35**	145	29
Energy	**25**	**30**	20	15	20	110	22
Waste Management	15	**25**	10	10	5	65	13
Building	15	15	15	**25**	15	85	17
Transport	10	10	**30**	20	**25**	95	19

As expected, Smart Cities was the most interconnected sector, as a hub where environmental, economic, and social sustainability efforts converge. Energy and Transport were the next most interconnected sectors, while Waste Management was the least interconnected to other sectors. In terms of CS goal intensity, Smart Cities lead, followed by Smart Energy, Smart Transport, Smart Buildings, and lastly, Smart Waste Management.

Various sectors present opportunities for different levels of CS goals. Smart Energy leads in Sustainability (CS1) and Resource optimization (CS2) goals, while Smart Transport leads in Real time data utilization (CS3) and Digital transformation (CS5) goals. Smart Waste Management is

disproportionately focused on Resource optimization (CS2) relative to all other goals.

Smart Energy remains highly dependent on Resource Optimization (CS2), attempting to use resources in a way that supports long-term sustainability. In contrast, Smart Transport and Smart Buildings are more dependent on Real-Time Data Utilization (CS3) and Digital transformation (CS5) and Climate adaptation (CS4), respectively. Overall, CS goals appear more prominent and perhaps better developed within Smart Cities, Energy and Transport sectors, while less prominent and less developed in Smart Waste Management and Smart Buildings. Table 2 also reveals that the Sustainability goal (CS1) is least developed in the Smart Transport, Buildings and Waste Management sectors, while the Climate adaptation goal (CS4) is, surprisingly, least developed in the Waste Management and Energy sectors.

On average (Table 3), the number of strong connections (1.6 per goal) is 33% higher than weak connections (1.2 per goal) across all CS goals. Both moderate and weak connections together (2.0 per goal) exceed strong connections (1.6 per goal) by 25%. Of notable concern, 50% of the weak connections are associated with Climate Adaptation (CS4), suggesting that climate resilience planning is not yet fully integrated into smart urban strategies. Additionally, Digital transformation (CS5) and Real Time data utilization (CS3), which underpin the technological dimensions, are yet to be imbued with climate adaptation goals. This implies significant room for enhanced interconnectedness among the sectors.

Table 3. Proportional distribution of the levels of interconnections among CS goals (CS1 – CS5).

CS goal	Strong	Moderate	Weak	Total
CS1	3	0	0	3
CS2	2	1	1	4
CS3	1	1	1	3
CS4	1	0	**3**	4
CS5	1	2	1	4
Total	8	4	6	18
Average	**1.6**	**0.8**	**1.2**	Av. 3.6

Figure 4 reveals how a CS goal like Sustainability (CS1) plays a crucial role as it is directly connected to 3 other goals (CS2, CS4, CS5); while Climate adaptation (CS4), is weakly connected to most other goals except to Sustainability, where there is a strong connection in the documents analyzed. Sustainability (CS1) is the most interconnected goal, emphasizing its role in uniting various CS goals. Its strong connections to Resource Optimization (CS2), Digital Transformation (CS5), and Climate Adaptation (CS4) indicate that sustainability is embedded within operational efficiency, technological advancements, and resilience planning. Thus, Sustainability does not function

as an isolated objective but instead depends on integrated processes that optimize resources, leverage digital tools, and incorporate data-driven strategies to support informed decision-making. These strong ties confirm that achieving Sustainability requires a system-wide approach that aligns technological progress with environmental objectives to ensure long-term urban resilience and efficiency.
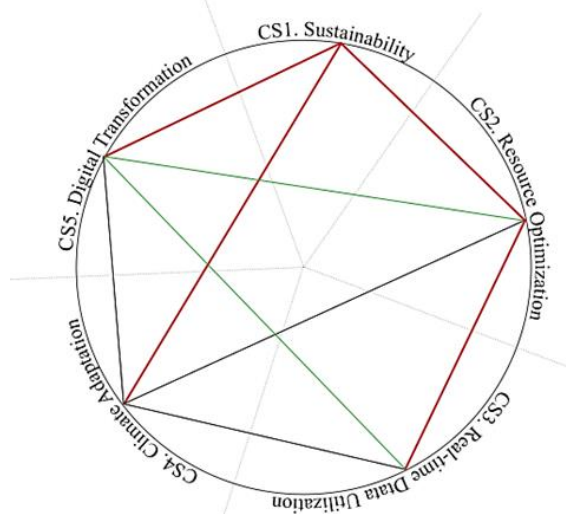
Figure 4. Interconnections among CS goals and applications. A red line denotes a strong connection, a green line denotes a moderate connection, and a black line denotes a weak connection.

Conversely, Climate Adaptation (CS4) remains the least integrated goal, exhibiting weak connections to most other goals and having only one strong link to Sustainability (CS1). This asymmetry exposes a significant gap where Resilience Strategies (CS4) are recognized but remain underutilized and insufficiently embedded within the broader framework of CS goals. The weaker ties indicate that while Climate Adaptation lacks the same level of operational, technological, and data-driven integration, which supports Sustainability, Resource Efficiency, and Digital Transformation. Thus, functions as an isolated rather than an integrated component of smart urban strategies.

Figure 4 also reveals a strong operational core centered around Resource Optimization (CS2), Real-Time Data Utilization (CS3), and Digital Transformation (CS5), which collectively drive efficiency, technological integration, and sustainability. The strong connections between these three goals underscore the role of optimization and data-driven approaches in improving urban efficiency. However, the weak connection involving Climate Adaptation (CS4) indicates that resilience planning has not yet been fully

incorporated into these operational and technological strategies, leaving a critical gap in the network of CS goals.

To strengthen the interconnections within the network, greater emphasis should be placed on reinforcing Climate Adaptation (CS4) as a core element of sustainable urban planning. This requires linking climate adaptation strategies to sustainability goals and embedding them into data-driven decision-making and resource management frameworks to enhance adaptability and long-term urban resilience.

Additionally, deepening the moderate ties between Digital Transformation (CS5) and Resource Optimization (CS2) could lead to new synergies, allowing digital innovations to drive resource efficiency more effectively. Similarly, enhancing the connection between Real-Time Data Utilization (CS3) and Climate Adaptation (CS4) could facilitate more dynamic and responsive resilience planning, ensuring that real-time analytics inform climate-responsive strategies and adaptive infrastructure development. This shows a need for transitioning from a more data-driven model to a more balanced approach that integrates operational efficiency, sustainability, and adaptive resilience: strengthening these interconnections is essential to ensuring that smart urban planning is optimized for technological and resource efficiencies and capable of withstanding long-term climate and environmental challenges. Subsequently, the detailed results from examining the distribution of interconnections for each CS goal and its sub-goals are presented.
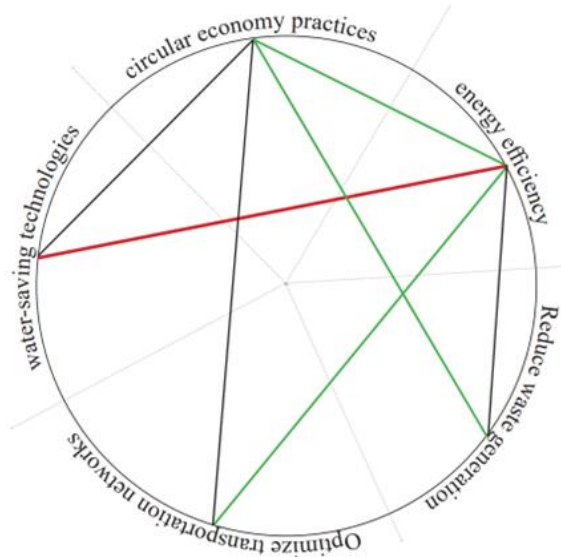
Interconnectedness of sub-goals within the Sustainability goal (CS1)
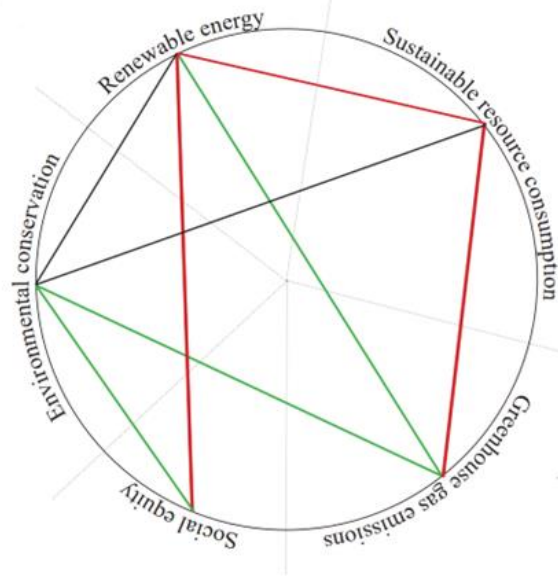
Figure 5. Interconnection of the sub-goals within the Sustainability goal (CS1) among the five sectors based on Pearson correlation coefficients generated from NVivo cluster analysis function.

Within the Sustainability goal (CS1), Renewable energy was strongly connected to Social equity and Sustainable resource consumption. Sustainable resource consumption and Greenhouse gas emissions are also strongly connected (Figure 5). However, Environmental conservation is weakly connected to Renewable energy and Sustainable resource consumption. Furthermore, Social equity did not have even a weak connection to Sustainable resource consumption or Greenhouse gas emissions. Thus, sustainability efforts lack strong integration with social justice and biodiversity conservation measures, emerging as priority areas for strengthening the interconnections.

Interconnectedness of sub-goals within Resource Optimization goal (CS2)

Figure 6. Interconnection of the sub-goals within the Resource Optimization goal (CS2).

Figure 6 underscores the fragmentation of resource optimization efforts, where Energy and Water efficiency exhibit strong interconnectedness, reflecting the recognition that water and energy systems are interdependent in urban sustainability planning. Moderate connections were observed between the Circular economy and waste generation and Energy efficiency, and between Energy efficiency and Transport networks. Circular economy was weakly connected to Water and Transport, and Energy efficiency was weakly connected to Waste generation, suggesting that the strategies are not yet fully aligned.

Interconnectedness of sub-goals within Real Time data Utilization (CS3)
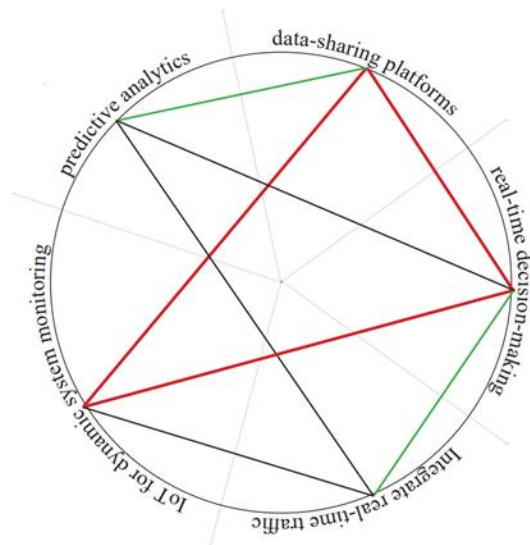
Figure 7. Interconnection of the sub-goals within Real-time data utilization (CS3).

In Figure 7, the strongest connections are between Data-sharing platforms, Real-time decision-making, and IoT for dynamic system monitoring, indicating that data utilization is most effectively leveraged when real-time data flows across platforms and supports automated decision-making in urban systems. However, weaker connections to Predictive analytics and Integrated real-time traffic suggest that while real-time data supports immediate decision-making, based on operational responses rather than future scenario modeling, its long-term forecasting and transport integration capabilities are less developed. This type of weak connection to Integrated real-time traffic implies that data-driven mobility management still lacks full integration into broader urban data-sharing and decision-making frameworks.

Interconnectedness of sub-goals within Climate Adaptation (CS4)
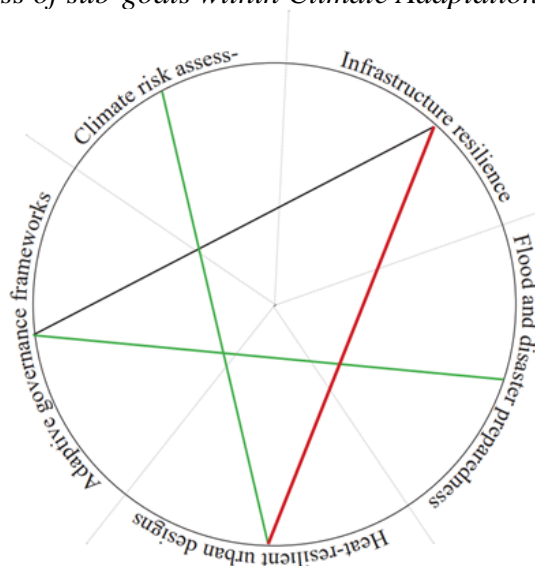
Figure 8. Interconnection of the sub-goals within the Climate Adaptation goal (CS4).

While the Climate Adaptation goal (CS4) connects to all other goals in the circle graph (see Figure 4), the strength of connections among its sub-goals varies. The strong connection is between Infrastructure resilience and Heat-resilient urban designs, emphasizing the critical role of built environment adaptations in mitigating climate-related challenges. This strong tie suggests that urban resilience strategies heavily rely on heat-resistant infrastructure, e.g. green building standards, and adaptive urban planning to counteract extreme heat events and other environmental stressors. However, the moderate connections between Climate risk assessment and Heat-resistant urban designs, and between Adaptive governance frameworks and Flood and disaster preparedness, indicate gaps in integrating proactive risk management, policy frameworks, and disaster response mechanisms within climate adaptation strategies. The lack of stronger connections in these areas suggests that while physical infrastructure is being reinforced, climate adaptation's broader governance and predictive risk assessment aspects remain underdeveloped.

Interconnectedness of sub-goals within Digital Transformation goal (CS5)

There is a strong link between Technologies, Integrated city dashboards and Digital governance, and Citizen engagement (Figure 9). While reflecting the increasing reliance on smart platforms for urban management and data-driven decision-making, the strong tie to Citizen engagement suggests that digital transformation plays a role in enhancing public

participation and digital inclusivity in governance frameworks. Moderate connections are between Cybersecurity and Citizen engagement, and also between Integrated city dashboards and Digital governance and Digital governance.
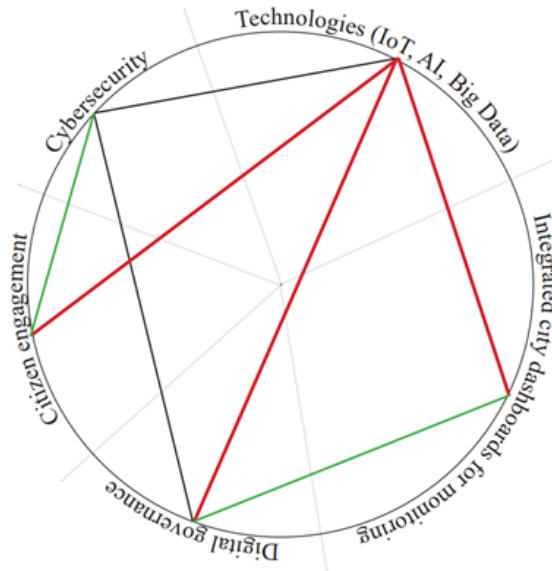
Figure 9. Interconnection of the sub-goals within Digital Transformation (CS5).

However, there is a weak connection between Cybersecurity and Digital governance and IOT, indicating a lack of robust integration with security measures and administrative cohesion. Furthermore, while digital and technological solutions are prominent, they were isolated without deep interconnections to broader sustainability sub-goals. This indicates that digital transformation primarily focuses on governance and monitoring rather than being embedded into transformational sustainability or climate-resilient urban strategies (Figure 9).

Interconnectivity from a Dendrogram

Patterns of convergence and divergence also act as markers of interconnectedness. The cluster analysis (Figure 10) reveals varying distances between goals, indicating the degree of alignment or interconnectedness in their focus and application. Goals that appear farther apart, e.g., Digital Transformation (CS5) and Real-time Data Utilization (CS3), on one end, and Sustainability (CS1) on the opposite end, implying the least interconnectivity between the two sets of goals.

Figure 10. Cluster analysis showing convergence/divergence patterns among CS goals and applications.

Interestingly, Sustainability (CS1), being farthest from the digital technology aspects (CS3 and 5), reveals that the application of technology was often not integrated with the sustainability agenda. Figure 10 also visualizes the worrisome distance between Resource Optimization (CS2) and Digital Transformation (CS5) goals. Clearly, exploring how to achieve deeper alignment and integration between these sets of goals remains an avenue for improved application of smart urban planning. Addressing these relatively low levels of interconnectedness will require a deliberate effort to integrate and calibrate these goals, ensuring that technological advancements, environmental sustainability, and social equity are aligned rather than at odds. Or put another way, analyzed synergistically rather than traded off against each other.

Discussion

Most of the interconnected CS goals (CS2, CS3, and CS5) are essentially operational in nature, targeting day-to-day activities. Outcome goals (CS1 and CS4), which can also be driven by the operational goals (Cai *et al.,* 2023), are relatively fewer in the network of goals. Notably, most CS goals and applications emphasize efficiency, digital transformation, and data-driven decision-making. It was also clear that digital solutions play a key role in enabling interconnectedness, although some applications were more interconnected with certain goals and not others. Goals exhibiting strong interconnectedness, such as those related to real-time data utilization and optimization, are learning grounds for an enhanced theoretically driven integration of goals, applications, and technologies in smart urban planning.

The findings also reveal important divergences in goals and applications, challenging the idea of seamless interconnectivity. The gap between resource optimization and climate adaptation highlights this divergence, as resource efficiency is often driven by short-term cost-saving measures, whereas climate adaptation and resilience planning require long-term investment in adaptive strategies. This weak interconnection suggests that optimization and efficiency-driven approaches are not yet fully interconnected/with transformational goals, e.g., sustainability or resilience.

Transformational goals, unlike short-term operational targets, refer to the fundamental changes, which are long-term, to be achieved through significant changes and ensuring that operational strategic objectives have been met. The term transformation captures the social, economic, environmental, and sustainability imperatives and aspirations of a nation, encompassing goals about climate adaptation and resilience, biodiversity and habitat or ecosystem services, etc. This reveals significant opportunities for exploring how to further connect different CS goals, especially those which are transformational (see Gjorgievski *et al.,* 2022), rather than reinforcing existing sectoral silos. Our results imply that achieving interconnectedness in these areas will enhance Sustainable Smart Planning Theory and Cyber-Physical Systems, which emphasize integrated, holistic approaches necessary for transformational smart urban outcomes. This will embed a necessary seamless integration of physical infrastructure with digital technologies (Andronie *et al.,* 2021), ensuring that technological advancements align with long-term environmental, social, and economic goals (Bruzzone *et al.,* 2021).

The key message is that while sustainability and digital transformation are essential pillars of smart urban planning, their interconnectivity remains underdeveloped, suggesting that technological advancements are not always leveraged in ways that directly support long-term sustainability and climate goals. Our results agree with Gazzola *et al.* (2019), who found that sustainability was not always a goal that is carefully considered and strongly connected with the digital technologies within smart approaches. Addressing these inadequate connections will require a shift towards optimization frameworks and digital transformations that are underpinned by transformational goals rather than solely focusing on technology-led efficiency and governance. We believe that a greater focus on interconnectedness will enhance the discourse and practice in several key works in urban systems theory, complexity science, and cross-sector urban governance (see e.g., Batty, 2013; Gehl, 2013), where interconnected and linked-up consideration of various urban systems is strongly advocated for.

While technologies offer a framework for sectoral interconnectedness, their effectiveness is likely constrained by limited interoperability across different applications across sectors. Smart Cities can function as effective platforms for sectoral interconnectedness, aggregating and analyzing data from multiple sectors, yet individual applications often deploy these technologies in narrowly focused and isolated ways. This lack of system-wide interconnectivity will limit the full potential of CS technological integration, reinforcing the need for 1) standardized protocols and collaborative digital frameworks that enable seamless data exchange and coordinated governance, and, 2) deeper theorization of how to bring about effective synergies across sectors.

This study contributes to the discourse on smart urban planning by highlighting the need for a more systematic, theoretical, methodical and analytical framework for deeper interconnectedness within the formulation and application of smart urban planning interventions. This seminal empirical insight is more generalizable and is valuable for asking practitioners and policymakers to consider aiming to leverage smart elements to achieve efficient and cost-effective smart outcomes. Essentially, it helps to reduce the risk that efficiency-driven and optimization-focused 'smart' approaches are not well interconnected within themselves and to broader sustainability objectives.

While Onyango *et al.* (2025) explored levels of convergence in three smart sectors (Energy, Transport, Waste Management), this paper goes further in scope to provide more generalizable insight based on key areas of strong, moderate and weak interconnectedness of the elements of smart (i.e., understandings, goals, applications). It does this across five sectors, which are very different in spatial nature and scales, thus providing insight that is underlaid with more nuance and complexity, as is typically inherent in practice.

This distinction in spatial scales underscores the different characteristics of smart sectors, where Buildings and Waste Management operate at localized scales, while Smart Cities function at a macro level (Han & Kim, 2024), integrating multiple sectors and extending across wider urban territories. This requires coordinated interconnectedness across various levels and dimensions of urban planning. Thus, potentially supporting the application of Cyber-Physical Systems (CPS) and Sustainable Smart Planning theories (Pacheco & Hariri, 2016), by enhancing our understanding of the profile of interconnectedness across at least five smart urban sectors. This can facilitate more targeted applications in digital transformation and real-time data utilization, and the integration of technological innovation with long-term sustainability and governance frameworks in urban planning (Machado *et al.,* 2023; De Jong *et al.,* 2015).

However, a key limitation of this paper is its lack of a narrower area of focus, e.g., regional-scale analysis to show how sectoral interconnectedness differs, especially regarding variations in smart planning approaches, policy and economic conditions. Future research looking at multi-regional comparative studies could provide deeper insights into how geographical and policy-specific factors influence sectoral integration, offering a more nuanced understanding of smart urban planning dynamics.

Conclusion and recommendations

The term smart has become a central concept in urban planning, reflecting a shift towards leveraging advanced technologies, data-driven strategies, and innovative practices to enhance urban efficiency, sustainability, and resilience. In this multi-dimensional perspective, the interconnectedness of urban challenges, such as energy efficiency, carbon emissions reduction, and housing sustainability, is well recognized, implying that smart solutions should emphasize holistic approaches. However, despite recognizing the concept of interconnectedness as crucial, the problem is that the extant literature predominantly addresses smart applications in isolated sectoral domains, e.g., Transport, Energy, and Waste Management, with limited emphasis on their inherent synergistic potential. This sectoral isolation can significantly hamper the realization of integrated and efficient urban sustainability.

This paper set out to explore the level of interconnectedness, viewed as the linking of smart elements, i.e., meanings, goals, and applications, between five smart sectors (Energy, Transport, Waste Management, Buildings and Cities). This was based on document analysis, informed by thematic analysis using codes of smart elements from documents identified by the PRISMA approach. The findings reveal that sectors like Smart Energy and Smart Transport demonstrated strong interconnectedness of smart elements, particularly in digital transformation, real-time data utilization, and resource optimization. However, Smart Waste Management and Smart Buildings exhibited weaker interconnectedness, particularly concerning sustainability and climate adaptation, highlighting gaps in the cohesive application of transformative strategies.

If optimizing smart elements for efficiency and cost-effectiveness is a central goal in urban planning, this paper provides seminal insight for considering areas for intervention, to increase the interconnectedness of smart elements. A well-conceived approach to coordinating the interconnectedness, sector-to-sector level or site-to-region or city scale levels of smart applications, has the advantage of a systems-wide approach to optimize urban functions. Where technological innovation, environmental stewardship, and social governance are not treated as separate domains but as interconnected components of a cohesive whole.

This paper's findings underscore the urgent need for frameworks that facilitate this level of integration via interconnectedness, thus ensuring that the potential of smart urban planning is fully realized in ways that are sustainable, adaptive, and inclusive. Research should focus on exploring the generation of threshold parameters and their metrics, for underpinning the consideration for appropriate levels of interconnectedness required across sectors. As this study was based on only five sectors, there is scope for more sectors to be included

in similar studies, across various jurisdictions, to explore not only the generalisability of the phenomenon of interconnectedness but also how to enhance it.

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Factors Influencing Farmers' Knowledge, Capacity, and Practice of Conservation Agriculture in Bangladesh

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Abstract

Conservation Agriculture (CA) is an alternative to the conventional farming system, which is considered a way of achieving climate-smart agriculture. Despite various CA support programs and promotional activities in Bangladesh, a major portion of CA farmers are reluctant to continue CA farming. This research aimed to reveal the extent and difficulties of continuing the practice and the gap between farmers' knowledge, ability, and performance. To collect data, we conducted a cross-sectional survey of 201 CA-adopting farmers from northern districts, namely Rajshahi, Rangpur, and Dinajpur. Results show that, among all components of CA practices in the area, most of the farmers regularly practice minimum tillage. The results also indicate that average income, access to and availability of machinery, and the knowledge gap are all commonly significant and have a big effect on the three dependent variables: the can-do gap, the know-can gap, and the know gap. The evidence indicates that reducing these gaps requires subsidies for resource-poor farmers and easy access to the machinery needed for CA practice. Public or private investments, or a combination of both, can effectively reduce these gaps.

Keywords: Conservation agriculture, Three gap model, Extent, Difficulties, Bangladesh

Introduction

This article deals with the extent of Conservation Agriculture (CA) practice among the farmers in Bangladesh and the difficulties they face, which influence the adoption of CA in the wider context. Like many other Asian countries, Bangladesh has low-input cropping systems dominated by cereal monoculture and rigorous tillage, which helps grow more diseases, weeds, and pests, resulting in decreased profit margins for the farmers. This very agricultural model, which is largely based on soil tillage, is not sustainable and is typically accompanied by adverse impacts on natural resources and the biodiversity of the soil. Continuing this traditional system will jeopardize the ecology of farming since this agricultural practice acts as a major driver of biodiversity loss and contributes to speeding up the loss of soil by enhancing the mineralization of organic matter and erosion rates (Corsi and Muminjanov 2019). In addition, the ever-growing population of Bangladesh demands greater productivity of food and the agricultural system as a whole (Gerland et al. 2014; GOB 2012; Hoque 2024). This concern remains at the heart of this discussion around food security in the age of increasing climate change threats in Bangladesh.

However, the concern is not just the quantity of food or yield, but also the quality of the food grains, products, land, and the environment around us. Continuous and persistent use of pesticides and chemically induced fertilizers without using organic materials and processes results in soil degradation and advances the decline of soil productivity and fertility (Kafiluddin and Islam 2008). In this critical time, the country requires a sustainable, smart, and eco-friendly farming system to provide food security for the growing population and increased income to improve farmers' livelihoods and to minimize the negative impacts on our environment. In this context, CA is an important alternative in overcoming these problems while improving production efficiency and soil health. Along with other climate-smart agricultural innovations, CA can increase yields, incomes, and farmers' welfare (Makate et. al., 2019). This practice is considered to advance a system avoiding or minimizing soil mechanical disturbance coupled with soil cover and crop diversification, which is a supportable agro-ecological method to resource-conserving agricultural manufacture (Corsi and Muminjanov 2019). As previously discussed, a complete adoption of CA is a contested issue. Various organizations and approaches have advanced the same idea with different conceptualizations. In this study, the basic principles theorized and propagated by FAO were considered. They are – (i) minimum soil disturbance (zero tillage

or reduced tillage), (ii) permanent soil cover in at least 30% of land in the form of crop residue or live mulches, and (iii) intercropping or crop rotation involving at least 3 different crop species (FAO 2019). The extent of the practice can be measured by these principles.

CA is a win-win approach that reduces operational costs, including machinery, labor, and fuel, while increasing yields and better utilizing natural resources (Roy et al. 2009; Hoque 2020). Considering the extent and difficulties of CA, Kassam et al. (2019) reported CA was being practiced on 106 million hectares of land around the world in 2008 and 180 million hectares in 2016, which is an increase of 68.5% in eight years. Perego et al. (2019) compared CA and CF and found that CA is more profitable and often less difficult than CF, and biological fertility increases for CA farming. However, the benefits attached to CA have been explored and examined in various studies (Abdulai and Abdulai 2017; Ghaley et al. 2018; Kaweesa et al. 2020; Pannell, Llewellyn, and Corbeels 2014; Pradhan et al. 2018; Shahzad et al. 2017). Only a few countries (i.e., USA, Argentina, Brazil, Australia and Canada) share 90% of CA land area, whereas South Asian countries have only around 2.77% of that land (5 million hectares) under this farming system (Biswas, Prativa, and Chaudhari 2017). This indicates that the extent and difficulties of CA practice are context-specific. Promotional strategies depending on farmers' knowledge of CA may unintentionally encourage the adoption of "no-till" alone, which has previously been shown to have negative effects on crop yields (Pittelkow et al. 2015). While discussing the real practice of CA, it was noted that conservation tillage is not conservation agriculture (Reicosky 2015). Therefore, limited and partial adoption of CA is related to socio-economic and agro-ecological constraints (Arslan et al. 2014; Giller et al. 2015). Giller et al. (2015) reviewed pertinent literature related to CA in developing countries and suggested that three components of CA adoption should be flexible based on the local context and farmers' socio-economic characteristics.

Despite having a great deal of potential, the adoption of CA is Bangladesh remains limited (Uddin et al., 2016; Hossain et al., 2015). This limitation is not just reflected in the number of farmers adopting this practice, but also in the area of land and the adoption of the principles. As Pannell et al. (2014) argue, the rate of adoption may vary due to the costs and risks of CA, and also on its benefits, availability of resources (human, land, or financial), or the farmers' risk preferences. Hossain (2017) explored several factors that limit CA in Bangladesh, including farmers' beliefs, peer pressure, lack of private sector investment, perceived difficulties, and environmental and health concerns.

In this backdrop, the aim of the study was to illustrate the extent of CA practices among farmers and the difficulties in continuing conservation

farming practices. Pagliacci et al. (2020), Rohila et al. (2018), and Tsige et al. (2020) identified the concept of "difficulties" in adopting climate-smart agricultural practices. Previous studies discussed the problems of the continuation of CA practices, which provided the basis of this survey (Akter et al. 2021; Dhar, Islam, and Ahmed 2017; Uddin and Dhar 2018; Dhar et al. 2018). However, studies related to the extent of CA farming practices and difficulties in continuing were not found. This study fills the gap and adds new knowledge in the context of the continuation of conservation agriculture.

Materials and Methods
Data Collection

The data for this study were collected in two phases among farmers from three districts located in the northern part of Bangladesh. The three purposively selected districts were Rajshahi, Rangpur, and Dinajpur. The reasons to include these three geographical areas are (a) agriculture was the primary livelihood of inhabitants (Tama et al. 2018), (b) these areas were reported to be hit by adverse climatic effects, including drought, lack of groundwater and flash floods (Islam et al. 2014; Hoque 2023; Tama et al. 2023), and (c) several international projects were carried out with a view to promoting climate-smart agricultural practices among the farmers in these areas (Tama and Hoque 2025). Farmers were selected using a multi-stage sampling technique. At the first stage, the authors carried out a purposive literature review to identify which geographical areas would be suited for data collection. This prompted the selection of the abovementioned three districts. At the second stage, six sub-districts were identified where many farmers adopted and practiced CA. At the third stage, a list of CA farmers was collected from the local agricultural research and extension offices. Finally, 201 CA farmers were selected for this survey. Although the number of female farmers was relatively small, female representation was ensured. While the survey was carried out in 2019-20, several focus group discussions (FGDs) followed.

Designing the Questionnaire

A structured questionnaire, which was divided into two major sections, was prepared to obtain the respondents' information. The first section collected information related to the socio-economic characteristics of respondents, including age, sex, formal education levels, farm size, cropping patterns, and physical assets. The second section encompassed the information regarding conservation agriculture, problems faced by CA farmers, and the extent of CA farming done by them.

Before finalizing the survey questionnaire, a series of activities, such as literature review, group discussions among agricultural experts and

researchers, pilot studies, etc., were conducted. Students from Bangladesh Agricultural University were hired and trained for data collection. During the data collection period, data enumerators collected most of the data in the local unit and then converted it to the standard and closely scrutinized it afterwards.

Analytical Technique

The study used descriptive statistics (average, maximum, minimum, percentage, etc.) and mathematical techniques (i.e., problem confrontation index) to achieve the objective of the study. The extent of CA farming practice was evaluated based on seven (7) components of this farming. Poddar et al. (2017) identified eight (8) components of CA practiced by Bangladeshi farmers. But in the selected areas, this study identified the following seven (7) components of CA that are commonly practiced by farmers. The components are zero tillage, minimum tillage, leaving crop residues in the field, following crop rotation, permanent soil coverage, applying green manure, and applying vermicompost. Farmers' opinions for each component were measured using a 4-point rating scale. This analytical method was previously used by Poddar et al. (2017) and Roy et al. (2015). Weights were assigned to these responses as 3, 2, 1, and 0, where 3 stood for regularly, 2 for occasionally, 1 for rarely, and 0 for not at all, respectively. The extent of CA practice was evaluated through descriptive statistics (e.g., average, number, percentage).

The pathways of translating knowledge to practice are always critical for any adoption-related studies and to understand the extent of practice. In the case of the adoption of CA in Bangladesh, correct assessment requires - (1) components of CA farming, (2) farmers' knowledge of these components, (3) farmers' ability or skills to correctly follow the components, and (4) farmers' application of this knowledge and skills in practice.

Ibnat et al. (2019) proposed the Three-Gap model starts with three measures of performance - performance, capacity, and knowledge - and three gaps: the gap between what a farmer should know (know gap) and what she or he should be doing (in relation to CA practice) and what she or he has the knowledge to do (the know-gap); the gap between what the farmers have the knowledge to do and their capacity to perform (the know-can gap); and the gap between what they have the capacity to do and what they do (the can-do gap). The three-gap model of the study is presented in Figure 1.

Farmers' knowledge was measured against the three components of CA farming. Their capacity was evaluated based on their capabilities to engage themselves in actual CA practice and whether the required machinery was available. For instance, if a farmer knows CA requires a power tiller-operated zero-tillage seeder, and that machine is unavailable or access to it cannot be obtained, capacity will be lower than knowledge. The performance was

measured with what farmers' actual behavior was (their extent of practice of CA).
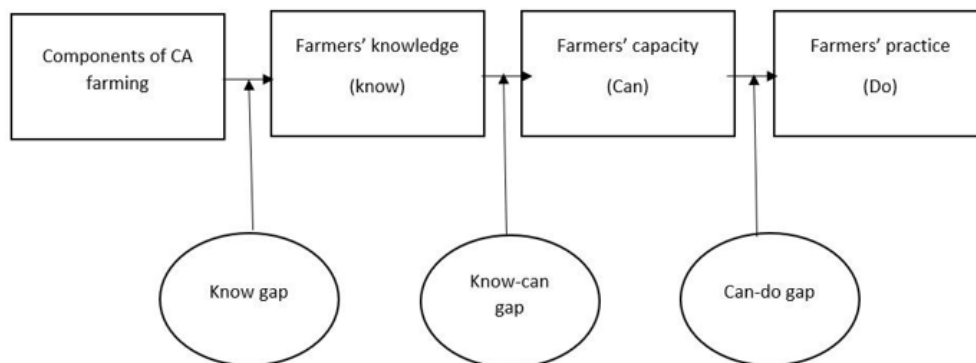
Figure 1: Pathways to farmers' knowledge to practice

The pilot survey was carried out among 30 farmers (who were not included in the final sample). Later, nine FGDs were conducted to explore the constraints. This pilot study was motivated by the secondary sources that identified some of the difficulties. The difficulties were recorded as opinion statements, which could later be used as part of the Problem Confrontation Index (PCI) analysis. This served to understand what interventions can be employed to target, influence, and alter those difficulties.

The problem confrontation index (PCI) score of the difficulties faced by CA-adopting farmers was computed and ranked according to the extent of difficulties faced by the farmers. Each farmer was asked to indicate the extent of difficulty caused by each of the problems by checking any of the four responses- 'High, 'Medium, 'Low and 'not at all', and weights were assigned to these responses- 3, 2, 1 and 0, respectively. Thus, the possible range of the problem confrontation score for each problem was from 0 to 3 and a possible range of the overall problem confrontation score for 12 difficulties ranged from 0 to 36. In this case, 0 indicated there was no problem and 36 indicated that the problem was very high. A problem confrontation index (PCI) for each selected problem was computed by using the following formula:

$$PCI = (Phigh \times 3) + (Pmedium \times 2) + (Plow \times 1) + (Pnot\ at\ all \times 0)$$

Where, Phigh = Number of responses indicating the problem occurred frequently. Pmedium = Number of responses indicating the problem occurred occasionally; Plow = Number of responses indicating the problem occurred rarely; and Pnotatall = Number of responses indicating no problem at all. Problem confrontation index (PCI) for any of the selected problems could range from 0 to 603 for CA farmers, where 0 indicated that the problem was

not faced at all by the farmers, 603 indicated that the problem was very high and frequently faced by the farmers. Finally, the required intervention matrix was provided by dividing the policy actions into three categories (policy intervention required, research required, and extension service required) for expanding conservation agriculture, which will be synchronized for policy options.

Results and Discussions

The study investigated farmers' constraints regarding the continuation of this farming practice and evaluated the strengths, weaknesses, opportunities, and threats of CA practice. Based on the findings, this study suggests a set of policy actions in the form of a recommendation matrix.

Extent of CA Practice

The summary results of practicing the components of CA are presented in Table 1. Results indicate that farmers in the study areas mainly practice minimum tillage (strip, reduced, and ridge). This minimum tillage requires specialized machinery (e.g., a power tiller-operated seeder, a power tiller-operated bed planter, a power tiller-operated strip tillage seeder, or a power tiller-operated zero tillage seeder). The following components are applying vermicompost, leaving crop residue, following crop rotation, maintaining permanent organic soil coverage, and applying green manure. CF practice requires more machinery, labor, cost, and time. On the other hand, zero tillage and minimum tillage require less input, like labor for plowing, and also lower costs since the need for machinery is lower, and also less time. This might be influencing the farmers more to use different components of conservation agriculture practices, especially minimum tillage. Several promotional strategies should be undertaken to diffuse the CA farming practice among the farmers. Findlater et al. (2019) focused on South Africa and found that there exists a miscommunication between farmers and local experts, which resulted in an inappropriate adoption of CA, which may hinderthe actual benefits of this farming practice.

The possible score for the extent of practicing CA components could range from 0 to 21. The observed practice score ranged from 5 to 21. The farmers were classified into three (3) categories according to the practice of components of CA, which is presented in Table 2. Findings indicate that the majority (79.10 percent) of the farmers had medium practice in CA components. This finding is supported by (Poddar, Uddin, and Dev 2017). So, the farmers in the study area practice particular components of conservation agriculture. Giller et al. (2015) argued that the components of CA should be flexible for farmers and the extent of practice depends on local and farmers' socio-economic contexts. Conservation agriculture does not necessarily

always increase crop productivity and farmers' incomes for small farmers (Descheemaeker 2020). Farmers who found the components of CA to be useful for them can adopt them according to his/her own preferences. Thus, all components of conservation agriculture should not be applicable as a common approach for all areas. Instead, the practice of CA farming should be flexible and adaptable according to local conditions (Mazvimavi et al. 2010)

Table 1: Extent of CA practice

Particulars	Extent of CA practice			
	Regularly	Occasionally	Rarely	Not at all
Practicing Zero tillage	71	98	29	3
Practicing minimum tillage (strip, reduced, ridge)	152	31	17	1
Leaving crop residue in the field	118	63	15	5
Following crop rotation	109	59	31	2
Maintaining permanent soil coverage	92	71	35	3
Applying green manure	63	51	80	7
Applying vermicompost	148	37	12	4

Table 2: Distribution farmers according to their extent of CA practice

Range of Possible Values	Observed Value	Categories	Farmers No.	Percentage
0-21	5-21	Limited extent (1-7)	39	19.40
		Considerable extent (8-14)	159	79.10
		Large extent (15- 21)	3	1.49
		Total	201	100

Three-Gap model

Table 3 presents the results of the multiple regression. Results show that the know gap is significantly and negatively influenced by CA farming experience, access to machinery, access to extension services, access to CA training, and average income. Several factors, including formal education, farming experience in CA, access to machinery and extension services, CA-related training, and average income, are statistically significant and have a negative impact on the know-how gap.

Table 3: Factors influencing Three-Gap (know, know-can, can-do)

Variable	Know gap		Know can gap coefficient	P value	Can-do gap coefficient	P value
Education	-0.092	0.213	-0.141	0.051	-0.206	0.006
Age	2.214	0.764	0.154	0.983	3.896	0.601
Farm size	-6.864	0.803	-0.940	0.971	-8.507	0.654
CA farming experience	-0.349	0.000	-0.149	0.003	0.371	0.470
Access to machinery	-0.721	0.000	-0.151	0.047	-0.581	0.066
Training experience	-0.183	0.319	-0.267	0.129	-0.341	0.052
Access to extension service	-0.285	0.018	-0.321	0.005	0.106	0.386
Access to CA training	-0.316	0.012	-0.249	0.039	-0.051	0.687
Average income	-0.474	0.0296	-0.215	0.041	-0.720	0.001
Average physical asset value	0.194	0.248	-0.031	0.846	-0.651	0.000
R^2	0.55		0.47		0.44	

This means that if the value of these factors increases, the Know-cap gap decreases accordingly. Among the explanatory variables, formal education, access to machinery, relevant CA training, average income and value of physical assets were found to be statistically significant. These factors negatively affect the Can-do gap. The results project that access to machinery and average income are commonly significant and significantly influence the three dependent variables – know gap, Know-can gap, and Can-do gap. This indicates that reducing these gaps requires subsidies for resource-poor farmers and easy access to the machinery needed for CA practice.

Extent of Difficulties Faced by the Farmers

Most of the farmers in the study areas started CA under the supervision of several national and international projects related to CA. The farmers were in the treatment group of those projects, and they received incentives and support to practice CA, and almost all CA farmers follow all the components of CA, including the three major principles. But after the completion of the project period, they faced difficulties related to inputs, especially access to machinery and its availability. Thus, the extent of practicing components of CA is decreasing day by day in the study area.

Table 4 shows the PCI for 201 CA farmers and the computed PCI score of the 12 problems, ranging from 314 to 555. The highest PCI score is for the category where the farmers faced the problem of lack of machinery required for CA farming - 157 farmers out of 201 in the study stated this as the major problem to continue CA practice. The selected farmers were not discouraged by their family members and friends, and the PCI score of this problem is the lowest (314) of all the problems.

Table 4: Extent of difficulties

Problems	High	Medium	Low	Not at all	PCI	Rank
There is a lack of specialized machineries in our area	157	41	2	1	555	1
If machineries do not work it is very difficult to repair it, as spare parts are not available in our area	120	65	12	4	502	4
Very few laborers can operate the machineries efficiently	97	52	49	3	444	9
I feel necessity of crop residue for livestock feeding	91	77	31	2	458	7
I feel pest and insects increased in my field	93	62	45	1	448	8
I receive less yield than the previous practice for minimum tillage	64	89	46	2	416	11
I notice weed infestation due to minimum tillage	117	53	29	2	486	6

Access to extension service is difficult for me	115	63	22	1	493	5
I feel that it is complicated to maintain three principles of CA	82	78	38	3	440	10
Lack of institutional credit for purchasing machineries needed for CA	155	36	9	1	546	2
I think there is a lack of government subsidy/support for CA practice	137	39	21	4	510	3
My family and friends don't encourage me to continue CA	62	45	38	56	314	12

The selected CA farmers were asked to give their opinions on the 12 selected problems that were identified during the pilot study and data collection. After computing the PCI score, the problems were ranked according to the PCI score.

Access to machinery is a critical problem stated by the farmers who are practicing CA, and it has the highest PCI score. This was the major problem faced by the farmers in the study areas. Specialized machinery (power tiller operated seeder, power tiller operated bed planter, power tiller operated strip tillage seeder, etc.) is needed for minimum soil disturbance planting in strip planting mode. Service providers of local machinery are making profits in the farmers' fields on a custom hire basis, but the number of these service providers is not adequate in Bangladesh (Hossain et al. 2014). Bell et al. (2018) suggested that an increase in the adoption and continuation of conservation agriculture practices in agriculture will require easy access for farmers to specialized machinery and an increased supply of machinery. Moreover, the performance analysis of newly invented CA machines is essential, and economic evaluation of CA technology at the field level is crucial for farmers (Tabriz et al. 2021). The 2nd highest PCI score belongs to the problem that farmers do not have easy access to formal credit to purchase inputs, especially the machinery required for CA farming. Formal credit systems (e.g., private or public banks, NGOs) require mortgages, several documents, and complex procedures, which farmers find difficult to manage. Institutional credit can play an important role in purchasing machinery and spare parts of the machinery. The findings of this study are supported by Uddin, Dhar, and Rahman (2017). According to CA farmers' perceptions, they lack government subsidies or incentives to support or continue CA farming. Lack of incentives fails to stimulate the adoption rate among non-CA farmers. Farmers also noticed that if any machinery does not work, then it is very difficult to repair as spare parts for this machinery are not available in local markets– this is the 4th highest constraint mentioned by the farmers. A noticeable number of farmers also stated that they do not have easy access to extension services. This problem has a high PCI score, and it is the 5th highest

ranked problem, opined to the farmers. Adoption and continuation rates of CA can be increased if the farmers can have easy access to the extension program. Dhar et al. (2018) found the lack of extension services available in the study areas to be a big problem noticed by the farmers, which further corroborates our findings. Access to proper information is strongly correlated with specific technology adoption (Khatoon-Abadi 2011). Chalak et al. (2017) found that farmers who receive practical knowledge and information about farming systems from extension agents have a higher probability of adopting CA farming compared to farmers who mentioned that they merely have contact with extension agents (but no knowledge and training). Farmers who have proper knowledge of CA farming are more likely to have behavioral intention to adopt this farming technique (Tama et al. 2021).

Farmers also noticed weed infestation due to lower tillage compared to conventional farming. The PCI score calculated for this problem is 486, which was the 6th highest PCI score. CA farmers stated that the crop residue that they left on the field could be used as animal feed or as fuel for household cooking. According to the farmers' perception, the PCI score for this problem was 458, ranking 7th in terms of PCI score. Most of the selected farmers stated that leaving crop residues in the field instead of using them for livestock feeding and fuel for cooking is one of the major challenges for them. Dhar et al. (2017) also found that one of the major problems of conservation farming is that farmers cannot use crop residue as animal feed or as fuel for household activities, which is similar to our study's result. The 8th and 9th highest PCI scores belong to the problems of an increase in pest and insect attacks, and the farmers' observation about the lack of experienced labor to operate the machinery, respectively. The PCI scores for the 8th and 9th highest problems were 448 and 444, respectively. According to CA farmers, maintaining the three principles of CA is complex and boring. The PCI score of this particular problem was determined to be 440 and was ranked 10th among 12 problems mentioned by the CA farmers. The 11th highest PCI score belongs to the problem that, due to minimum tillage, CA farmers receive less yield than conventional farming. This has a PCI score of 416. Finally, the 12th and lowest PCI score belongs to the issue of farmers' friends and family members not encouraging them to continue CA farming. This has a PCI score of 314. This result is similar to the findings of Hossain (2017), who identified that peer pressure is a major obstacle in the adoption and continuation of CA in Bangladesh.

Recommendation Matrix

Based on the findings of the study, a set of policy actions is suggested to increase the adoption rate as well as the diffusion of this technology in Bangladesh. The required intervention matrix (Table 5) is presented in three

categories: policy interventions required, research required, and extension services required.

Table 5: Required intervention matrix for future actions

Items	Actions and policy intervention required	Research required	Extension service required
Provide easy loans for purchasing machinery required for CA farming	√		√
Ensure farmers' easy access to agricultural technology, equipment, and machineries	√		√
Enhance the farmers' knowledge about CA	√	√	√
Arrange training programs on CA regularly			√
Organize 'Field Day' frequently and regularly to discuss the problems faced by farmers in practicing CA			√
Promotional strategies should be increased	√		√
Enhance direct input subsidies	√		
Arrange training program to operate machinery required for CA farming	√		√

Conclusion

This study looked into the challenges that CA farmers face, how much they are using this farming method, and suggested a plan to help improve the use and ongoing practice of CA farming in Bangladesh. Findings of the study reveal that most of the CA farmers were practicing considerable components of CA. The extent of CA practice should be flexible to the farmers' socio-economic, farming, and local conditions. The results also indicate that many farmers opined that the lack of machinery was the major problem in the study area. Thus, this study suggests that providing easy loans to farmers to purchase the machinery required for CA farming is important to stimulate the adoption and continuation rate. Extension service providers can transfer knowledge and updated information about CA farming and discuss the benefits and challenges of CA farming, which can positively influence farmers to continue CA farming. Extension agents can organize "field days" frequently and arrange regular workshops and training programs to discuss the difficulties faced by farmers and provide possible solutions to the farmers in the study areas.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration for Human Participants: This study has been approved by the Huazhong Agricultural University, China and the principles of the Helsinki Declaration were followed. Consent to participate: The authors obtained consent from the farmers before interviewing them. They provided oral consent to publish the data.

Authors' Contribution
Riffat Ara Zannat Tama: Conceptualization, Methodology, Investigation, Data Curation and Writing – Original Draft; **Liu Ying:** Software, Validation, Writing- Reviewing and Editing; **Md Mahmudul Hoque:** Visualization and Writing- Reviewing and Editing.

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How the Adoption of Government Interventions has Affected Income Inequality and Poverty in Some African Countries

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Abstract

The majority of Sub-Saharan African (SSA) nations continue to have higher rates of poverty than other developing nations in comparable parts of the world. To reverse this situation, the World Bank established the seventeen Sustainable Development Goals (SDGs), which aim to reduce income inequality and end extreme poverty by 2030, while also increasing the shared prosperity of the lowest 40% of each nation's population. Hence, the governments of African countries have implemented several policies to achieve this goal. This paper examines how the implementation of these policies has impacted poverty and income inequality in six African countries: Nigeria, Cote d'Ivoire, South Africa, Mozambique, DR Congo, and Tanzania, comparable to Ghana. Machine Learning was applied to achieve this objective. The results showed that, while agriculture expenditure has a positive impact on income inequality in Nigeria, Mozambique, and DR Congo, as in Ghana, agriculture expenditure has a negative impact on income inequality in Cote d'Ivoire and Tanzania. Regarding poverty, agricultural expenditure has a positive relationship with poverty in Côte d'Ivoire, South Africa, Nigeria, Tanzania, and DR Congo, but a negative impact on poverty in Mozambique, as was the case in Ghana. Generally, there was a mixed relationship between government policies and both income inequality and poverty across the six countries, as was also the case in Ghana. In addition, the policies implemented have different impacts on poverty and income inequality in the various countries. This implies that policies that help reduce poverty are not necessarily the same as those that help reduce income inequality.

Keywords: Income Inequality, Poverty, Government Interventions, Expenditure, Machine Learning

Introduction

In 2000, world leaders adopted the Millennium Development Goals (MDGs), with the primary goal of eliminating extreme poverty and hunger and narrowing the inequality gap by 2015 (United Nations Development Programme, 2015). The MDGs, which helped over a billion people out of extreme poverty [US $1.25 per day], were deemed by former UN Secretary General Ban Ki-Moon to be among the most significant initiatives for reducing poverty (United Nations Development Programme (UNDP), 2015). Despite these advancements, there was still widespread poverty and income inequality, particularly in developing nations. For instance, in 2013, 48% of people in Sub-Saharan Africa were still living in extreme poverty, defined as earning less than $1.25 a day (UNDP, 2015). According to the World Poverty Clock's June 2018 report, 86.9 million Nigerians were living on less than $1.90 per day (Aderounmu et al., 2021). By February 2019, over 3 million more people had fallen into poverty, bringing the total number of impoverished Nigerians to over 91 million. In comparison to certain other African nations, Nigeria had the highest number of people - 86.9 million - living in extreme poverty, followed by Tanzania, Kenya, South Africa, and Zambia, with respective numbers of 19.9 million, 14.7 million, 13.8 million, and 9.5 million (Aderounmu et al., 2021). The World Bank (2018) projected that by 2030, "nearly 9 of every 10 people in extreme poverty will be living in Sub-Saharan Africa," making the trend concerning. Global severe poverty is decreasing in all regions, but it is rising in Sub-Saharan Africa (Wadhwa, 2018). Furthermore, all developing nations have the highest levels of inequality in the world, and the majority of these nations are in Africa (Fofana et al., 2023). Extreme poverty, both relative and absolute, is concentrated in low- and middle-income countries (Cuesta et al., 2018).

According to Beegle and Christiaensen (2019), the majority of Sub-Saharan African (SSA) nations, especially most of the countries selected for the study have higher rates of poverty and inequality than other developing nations in comparable parts of the world. According to World Bank data (2022), South Africa recorded the highest income inequality with a Gini index of 57.7 in 2018, followed by DR Congo at 51.2 and Mozambique at 50.5, both in 2019. In Tanzania, inequality increased, with the Gini index rising from 38 in 2011/12 to 40 in 2018. Income inequality in Cote d'Ivoire and Nigeria was quite lower than the record in Ghana. The Gini index for Cote d'Ivoire and Nigeria were 37.2 and 35.1 respectively, while the Gini index in Ghana was 38.3 in 2018. In 2015, the poverty rate in Côte d'Ivoire was 46% of the

population (World Bank, 2017), while Mozambique recorded a slightly higher rate of 48.4% in the same year. In 2022, nearly 62% of Congolese were living in poverty. In 2018, Tanzania's poverty rate - measured at $2.15 per day (2017 PPP) - was 44.9% of the population. It is astonishing that these Africa countries remain impoverished despite having abundant natural resources (agricultural, petroleum, gas, enormous untapped solid mineral deposits, and human capital) (Aderounmu et al., 2021).

While poverty and income inequality have long been issues in many nations, different governments have tried a variety of policies to address the issue (Afful, Nunoo & Arthur-Biney, 2019). Eliminating poverty has evolved into a new kind of world war rather than merely a problem for one nation. This is because poverty and income disparity have the capacity to undermine social welfare initiatives and erode earlier growth (Cuesta et al., 2018). A 2005 study on the Economic and Social World Situation highlighted the problems of inequality and argued that everyone would suffer if an inclusive, integrated growth strategy was not pursued. This illustrates how complicated inequality is and how urgently it needs to be addressed. Thus, the question of how these resource-rich countries can have a sizable portion of their populations living in extreme poverty remains unanswered. The failure of the Millennium Development Goals to reduce income inequality and halve the number of people living in poverty by 2015 is still difficult to comprehend. Without significant attention, it is estimated that these countries will not be able to meet the Sustainable Development Goals by 2030 (Yoshida et al., 2014; Lakner et al., 2014). The lacklustre achievement casts serious doubt on the policies and strategies used to reduce poverty and income inequality. These situations underscore the necessity of addressing the poverty issue and understanding its implications on a country's ability to develop. To achieve this, the World Bank established the seventeen Sustainable Development Goals (SDGs), which aim to reduce income inequality and end extreme poverty by 2030 while also increasing the shared prosperity of the lowest 40% of each nation's population (Abaidoo, 2021). Therefore, examining each competing factors will enhance informed policy intervention towards poverty and income inequality.

To achieve the objective of the study, six countries were selected: Nigeria, Côte d'Ivoire, South Africa, Mozambique, DR Congo, and Tanzania. They were chosen for several reasons, as explained below (pp. 4).

This study contributes to the body of research by examining major government policies implemented in these six African countries, which employed different methods and had varying levels of resource endowment, through some empirical exercises. To address the limitations posed by data deficiency, a common challenge in the studies of nature, the analysis also employed Machine Learning estimators, providing more robust and reliable results to address the data deficiency issue. These techniques may offer a better

understanding of the impact of government initiatives on poverty and income disparity in Africa and help inform policy changes in the selected countries. The remaining paper is structured as follows: Section 2 focuses on stylized facts; Section 3 provides a brief review of the main approaches and driving forces behind poverty and income inequality reduction; Section 4 presents the data, and the methods used; Section 5 examines and discusses the empirical findings; and Section 6 concludes.

Stylized Facts
General Overview

Six countries were selected for the study: Nigeria, Cote d'Ivoire, South Africa, Mozambique, DR Congo, and Tanzania. The focus on the selected countries was motivated by four reasons. Firstly, like Ghana, these countries rely on agriculture, were exposed to European colonization, have large rural populations, and experience high income inequality and extreme poverty. Secondly, like Ghana, they have a large informal sector, which operates beyond government taxation and oversight. Thirdly, there is generally a scarcity of data on this topic in Africa. However, these countries have comparatively more data available for the study. Fourthly, significant similarities can be anticipated in their social programs, given their strong economic, cultural, and social similarities. However, some countries implement social programs differently from Ghana, while others follow a similar pattern. In Tanzania, Nigeria, and Mozambique, the government has generally attempted to strengthen the informal social welfare systems of the extended family and community through a more decentralized social policy, similar to Ghana. In contrast, the governments of Côte d'Ivoire, South Africa, and DR Congo have sought to replace these informal social networks with the centralized bureaucracy. Various nations have implemented comparable changes differently, particularly in terms of the timing of the reforms and how vulnerable populations were addressed. Therefore, it will be interesting to examine how government interventions affect income disparity and poverty in nations where the implementation is similar to Ghana, compared to those where it is not.

Indicators of poverty and income growth for selected nations are displayed in Table 1, along with the Sub-Saharan African averages for the same indicators. Except for South Africa, Ghana, Tanzania, the Democratic Republic of Congo, and Cote d'Ivoire, whose annual GDP growth and GDP per capita growth rates exceed the SSA average of 4.2% and 1.5%, respectively, all other selected countries experienced low GDP growth during the chosen period. Growth in Africa was slower in 2021, compared to many other regions of the world. This supports Ibi-Ajayi's (2002) conclusion that "the growth performance of many African countries has been disappointing

(or dismal) over several years, notwithstanding the isolated cases of Botswana, Mauritius, and Morocco". The Central African Republic, Namibia, and South Africa have the highest rates of income disparity. This also supports the International Monetary Fund's (IMF) assessment that, when measured by real GDP, the income disparity between Sub-Saharan Africa and the rest of the world is widening (Majekodunmi et al., 2023).

Table 1. Income Growth and Inequality Indicators for Selected Sub-Saharan Africa Countries[1]

S/N	Country	GDP Growth (Annual %) in 2021	GDP per Capita Growth (Annual %) in 2021	Income Share held by the highest 20% (a)	Income Share held by the lowest 20% (b)	Gini Index (c)
1	South Africa	4.9	3.9	68.2	2.4	63.0
2	Namibia	2.7	1.0	63.7	2.8	59.1
3	Central African Republic	0.9	-1.2	60.9	3.3	56.2
4	Mozambique	2.4	-0.5	56.1	4.4	50.5
5	DR Congo	6.2	2.8	48.4	5.5	42.1
6	Tanzania	4.3	1.2	48.1	6.9	40.5
7	Ghana	5.1	3.0	48.6	4.7	38.3
8	Cote d'Ivoire	7.0	4.4	44.7	7.0	37.2
9	Nigeria	3.6	1.2	42.4	7.1	35.1
10	Sub Saharan Africa	4.2	1.5	N/A	N/A	N/A

Source: World Bank's World Development Indicators (2022)

Human development and poverty indicators on the continent, including the six countries under study, have not improved as predicted, even though many African nations have had rapid economic growth over the last ten years (Asongu, Orim & Ntig, 2019; Shimeles & Nabassaga, 2018). Significantly, due to rapid population growth, the number of impoverished people in Africa has increased (from 278 million in 1990 to 413 million in 2015) (World Bank 2018).

Geographically, poverty in Africa is concentrated in two countries: Nigeria and the Democratic Republic of Congo. These two nations, which are commodity exporters, bear a major portion of the continent's poverty burden (Hamel et al., 2019). Around 12 percent of the global population living in extreme poverty in 2023 - where the poverty line was set at 1.90 US dollars per day - was based in Nigeria (see Figure 1). To make matters worse, approximately 10% of the world's population living in extreme poverty was in the Democratic Republic of Congo. Tanzania, South Africa, and Mozambique

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[1] NOTE: The figures quoted in (a), (b), and (c) are for various years between 2010 – 2020

were also among the African countries with impoverished populations. Among the countries selected for the study, only Cote d'Ivoire had a lower rate of poverty than Ghana; all the other five countries recorded higher poverty rates.

Figure 1. Share of Global Population Living in Extreme Poverty by African Countries
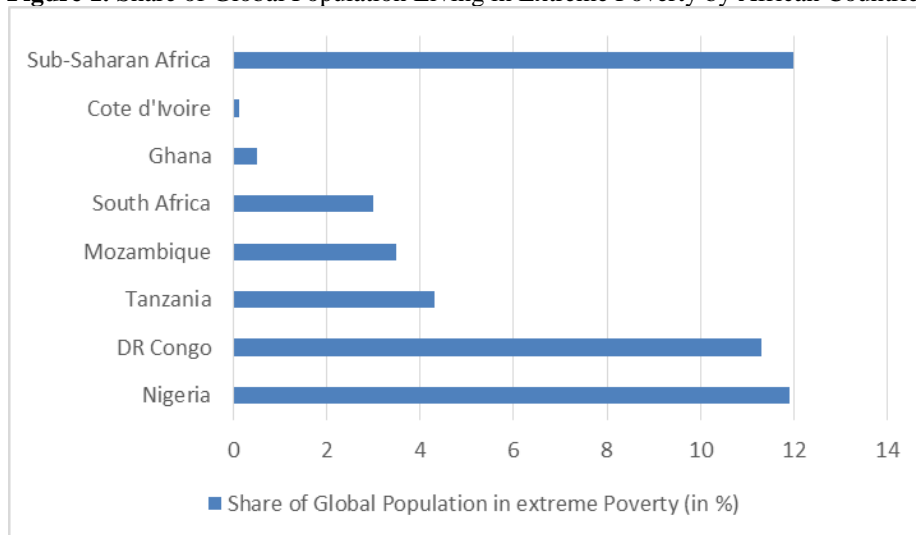
Source: Statista (2023)

Africa is the second most unequal continent after Latin America, according to the Gini coefficient. In 2021, eight African nations ranked among the top ten most unequal globally, with South Africa and Namibia occupying the top two spots (Majekodunmi et al., 2023). This persistent trend presents a highly alarming picture of the state of inclusive growth on the continents and underscores the urgency with which policymakers must act to reduce poverty and income inequality, both of which are critical to advancing human welfare.

What Measures have been Undertaken to Limit Poverty and Income Inequality in Africa?

While a number of African nations have experienced robust economic growth over the past ten years, the continent's poverty and human development indicators have not improved as anticipated (Asongu, Orim & Ntig, 2019; Shimeles & Nabassaga, 2018). Nonetheless, several nations have made progress in reducing poverty and income inequality.

In the early decades following independence, the key determinants of income inequality and poverty included the structure of the economy, asset allocation, return on assets, and redistribution policies in both cash and kind (UNDP, 2017). Molini and Pierella (2015) identified structural reform, increased labour force skill, and spatial mobility as the main drivers of poverty reduction in Ghana between 1991 and 2012. South Africa, through the

Reconstruction and Development Programme (RDP), introduced reforms similar to countries like Mozambique, Nigeria, DR Congo, and Tanzania to cater to the citizenry. Cote d'Ivoire, after undergoing a series of political instability, is implementing structural reforms in an effort to reduce poverty. Mozambique is transforming its agricultural sector by encouraging smallholder farmers to engage in market-base agriculture. According to Silva (2013), a vast majority of rural households earned higher incomes between 2002 and 2005, thereby improving living standard. A cornerstone of South Africa's social insurance system, and similarly for several countries under review, is unemployment insurance. This provides essential resources to individuals unable to work due to age, disability, or other reasons (Old Age Pension, Disability Grant, and Child Support Grant), or who need additional income to support their children (Leibbrandt et al., 2011). The Basic Income Grant (BIG) implemented in countries such as South Africa, Cote d'Ivoire, and DR Congo has also helped in mitigating the plight of the poor.

Efforts to promote social cohesion and conflict resolution are additional steps taken by African governments to address poverty and inequality (UNDP, 2015). Randomized controlled trials have shown increased social cohesion in targeted settings through interventions such as truth and reconciliation commissions and community-based development programmes (Casey, Glennerster & Miguel, 2016). According to M'Bayia (2015), the poverty and inequality situation in Cote d'Ivoire worsened during the period of military, social, and political crisis. However, following the return to economic stability in 2011 and the implementation of aggressive poverty reduction strategies, the poverty rate reduced drastically. According to World Bank (2016) reports, Mozambique's poverty rate also declined significantly following the end of the civil war, similar to the reduction in poverty and inequality observed in Ghana after the return to democracy. Abidoye and Calì (2021) attributed the unwavering change in poverty and inequality in Nigeria to intermittent conflicts brought by the Islamic militant groups. Leibbrandt et al. (2011) also cited apartheid and the inter-racial conflicts in South Africa as primary contributors to high inequality, noting that improvement in social cohesion has since led to a gradual decrease in the inequality gap. In the case of DR Congo, the slow pace of poverty and inequality reduction has been attributed to a long history of conflict, political upheaval, and instability.

According to Beegle and Christiaensen (2019), the cancellation of foreign debt in nations qualified for the Heavily Indebted Poor Countries (HIPC) Initiative resulted in a noticeable decrease in the Gini coefficient by creating more fiscal freedom. Inequality also declined in several countries, such as Tanzania, DR Congo, Mozambique, South Africa, and Ghana, due to increased targeted social investments and a rise in direct taxation as a share of

total revenues (UNDP, 2015). Expanding such programmes could lead to significant benefits.

Poverty-related strategies embedded in development policy frameworks have also contributed to the reduction in poverty and inequality across Africa. Prior to the creation of Vision 2020, all districts and regions participated in the national development goal-setting exercise, preceded by the Human Development Strategy for Ghana (1991) and the National Development Policy Framework (1994) (Ofori-Boateng & Bab, 2015). Mozambique's Five-Year Development Plan (2000–2004) identified poverty reduction as a central objective (Government of Mozambique, 2000, 2001). In Kenya, an unconditional cash transfers programme significantly reduced the incidence of depression among young males (Kilburn et al., 2016). Qualitative evidence from Zimbabwe, Lesotho, and Ghana also suggests that cash transfers promote mental health (Attah et al., 2016). In Nigeria, various programmes, such as the Structural Adjustment Programme (SAP), the National Poverty Eradication Program (NAPEP), National Economic Empowerment and Development Strategy (NEEDS), Free and Compulsory essential Education (FCPE), Better Life Programme (BLP), and the Subsidy Reinvestment and Empowerment Programme (Sure-P) were introduced to combat poverty and inequality (Adamu & Inuwa, 2016; Hussaini, 2014). Accelerating the financial inclusion of the impoverished population who are not part of the formal financial system is one of the initiatives the administration has adopted in Cote d'Ivoire. Additionally, to reinforce the fundamental social security guarantees for the most disadvantaged people in Cote d'Ivoire, a national plan to encourage microfinance was launched in 2007, along with the gradual creation of a social protection system. All these programmes, in one way or another, helped reduce poverty and income inequality on the continent.

Methods
Methods for Evaluating Poverty and Income Inequality: A Synthesis

Numerous scholars from around the world have been tasked with finding solutions to the persistent and expanding income gap, policy mismatches in addressing income inequality, and the challenge of relative poverty (Heshmati & Kim, 2014). According to Stiglitz (2012), inequality undermines the foundations of the economy and fuels instability. Addressing these persistent economic issues will remain extremely difficult if income disparity and poverty are not properly understood.

Income Inequality: The concept of inequality often causes confusion in public deliberation, as it tends to mean different things to different people (Gallo, 2002). However, inequality refers to comparability between elements, typically assessed based on specific features that can be measured using

appropriate indexes (Gallo, 2002). Income inequality can be measured across economic and social dimensions (Afful, Nunoo & Arthur-Biney, 2019).

There are several methods for measuring income inequality. However, the Gini coefficient has remained the most popular method for operationalizing income inequality in the literature (De Maio, 2007).

Poverty: Poverty is a multidimensional concept that captures various levels of deprivation encountered by a person, household, or community. Although much of the literature focuses on indicators such as income, food security, and access to housing, the selection of indicators to measure deprivation can be arbitrary. As a result, these measures may fail to fully reflect unmet basic needs in different social and cultural contexts. This discrepancy often leads to terms such as poverty, social exclusion, and vulnerability being used interchangeably in development discourse.

A Formal Framework

To address the missing values and the lack of a large data set, the study employed a machine learning regression model, such as the Elastic Net Regression. ELNET regression is a combination of two best techniques of shrinkage regression methods, namely, Ridge regression ($L2$ penalty) for dealing with high-multicollinearity problems and the LASSO regression ($L1$ penalty) for feature selection of regression coefficients (Wang et al. 2019; Buell et al. 2021). The formal model is as follows:

$$h_{it} = \alpha + \beta_i M_{it} + \sum_i \gamma_i G_{it} + \delta_{it}$$

(1)

Where h_{it} represents the dependent variable i (i=1,2) at time t, M_{it} represents the control variable i at time t, G_{it} represent the explanatory factor i at time t, β_i represents the coefficient of M_i and γ_i represents the coefficient G_i.

The Data

The empirical analysis was conducted on an annual basis over the period (1987–2019). All data were sourced from the World Bank's World Development Indicators. Due to significant gaps in the data, a simple interpolation method was employed to fill in the missing values. The revised dataset was then tested for stationary using the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1981). The results of the unit root test, which showed many missing values, are displayed in Appendix 1. All series were found to be stationary at the first difference.

The descriptive statistics summarize the values of the variables over the study period (1987-2019). These statistics for Nigeria, Cote d'Ivoire, South Africa, Mozambique, Tanzania, and DR Congo are reported in Appendix 2. From the results, the mean value for AGRIC ranges from -0.17 to 1.5 across the six countries, with DR Congo recording the lowest mean (-0.17) and Tanzania the highest (1.5). This indicates that, although DR Congo has the largest arable land in Africa, it is not being effectively utilized. DR Congo also shows the highest variation in agricultural performance, with a standard deviation of 1.4, while the other countries (Nigeria, South Africa, Tanzania, Cote d'Ivoire, and Mozambique) all recorded standard deviations below 1.

Regarding education expenditure, DR Congo recorded the highest average (7.2) with a standard deviation of 6. Mozambique and Tanzania each recorded a mean of 3.6, with standard deviations of 1.9 and 0.8, respectively. South Africa recorded a mean of 5.1 (SD=0.5), Cote d'Ivoire 3.9 (SD1.5), while Nigeria had a negative mean value of -13 with a standard deviation of 11. This suggests that despite Nigeria's abundant resources, investment in the education sector remains insufficient. In the health sector, average expenditure ranged from 0.2 to 2.7, with South Africa having the highest mean investment (2.7) and DR Congo the lowest (0.2). It is therefore not surprising that South Africa is often considered the preferred destination for healthcare within the continent.

Social protection expenditure ranged between -12 and 52. South Africa had the highest mean investment (52), while Nigeria recorded the lowest (-12). Transport expenditure averaged between -14 and 14, with Mozambique having the lowest investment (mean = -14), and South Africa the highest. In addition, the mean value for the Gini index ranges from 37 to 60 across the six countries, with Tanzania recording the lowest mean (37) and South Africa the highest (60). This confirms that South Africa has the highest income inequality in Africa. Finally, Tanzania also recorded the highest mean poverty (69.8), followed by DR Congo (69.8), Mozambique (43.1), Nigeria (18.3), and South Africa (10.4)

Results and Discussion
The Benchmark Model

The independent variables are conceptualized as follows: Coverage of social protection and labour programs (% of population) (SOCIAL); Machinery and transport equipment (% of value added in manufacturing) (TRANS); Domestic general government health expenditure (% of GDP) (HEAL); Agricultural raw materials imports (% of merchandise imports) (AGRIC); and Government expenditure on education, total (% of government expenditure) (EDU), with GDP growth (annual %) (GDP) as a control

variable. The dependent variables are poverty level, represented by the Poverty gap at \$1.90 a day (2017 PPP) (%) (POV), and income inequality represented by the Gini Index (GINI). Equation 1 is thus transformed into its operational form as follows;

$$h_t = \alpha_0 + \alpha_1 AGRIC + \alpha_2 HEAL + \alpha_3 TRANS + \alpha_4 EDU + \alpha_5 SOCIAL + \delta_t \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

The Estimate of the Benchmark Model of the Impact on Income Inequality

The study adopted a machine learning regression model, specifically the Elastic Net Regression. The results regarding the impact of government policies on income inequality are presented first.

Table 2 shows the impact of government expenditures used to implement various policy interventions on income inequality. Figure 2 presents the trace plot of the model. As illustrated in Figure 2, the Elastic Net algorithm shrinks the coefficients of the predictors to enhance the prediction power of the model. As the value of lambda increases, the coefficients shrink further, reducing variance and improving the model's suitability for out-of-sample prediction.

Figure 2. Elastic Net Trace Plot for the Six Countries
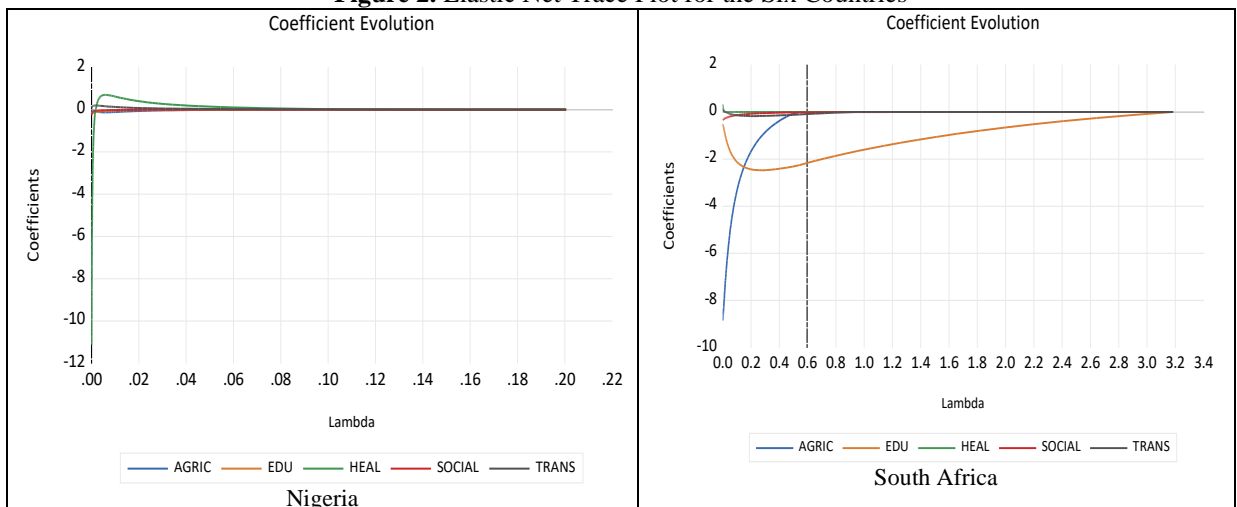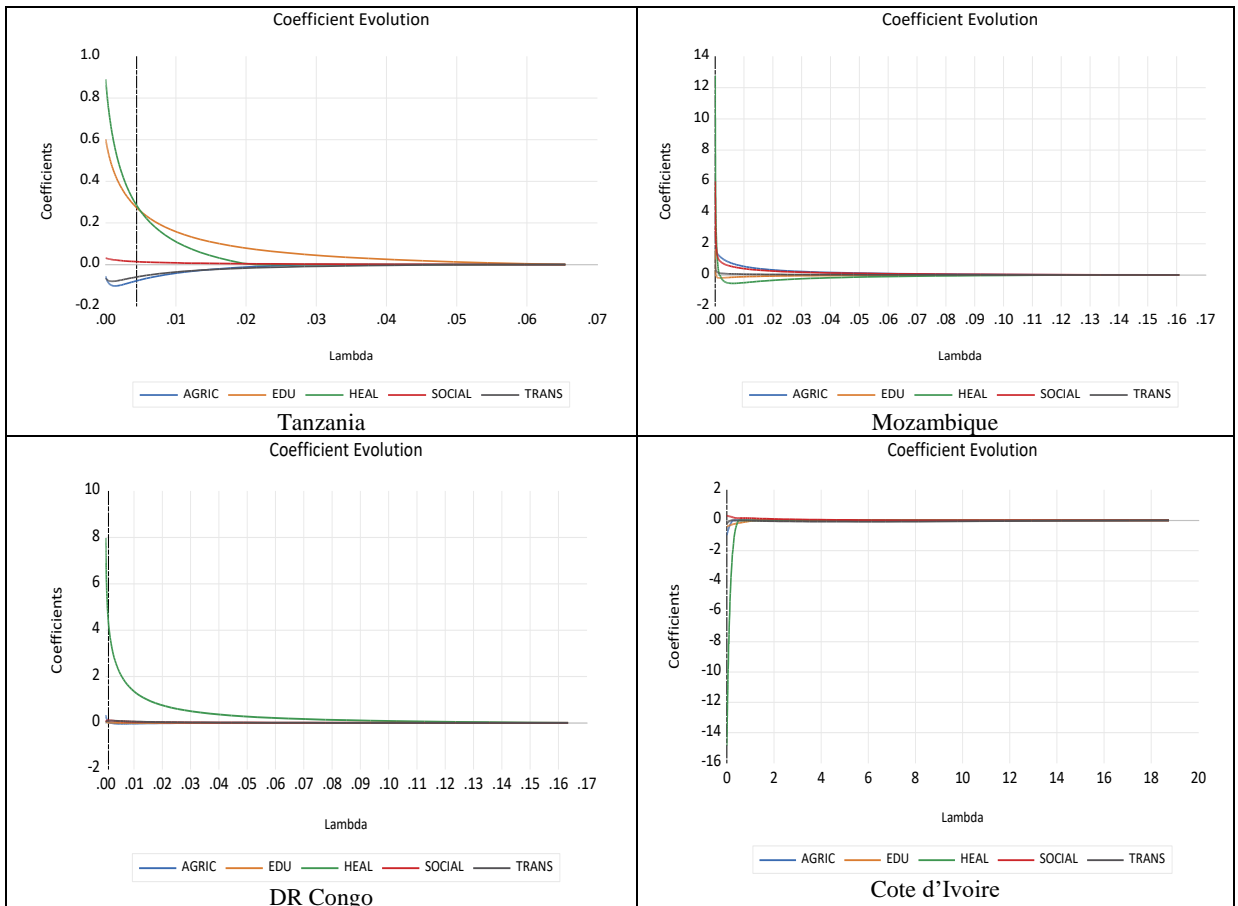
Source: Author's Calculation

Applying the "one standard error" rule to select the optimal tuning parameters appears overly aggressive in this model, as it suppresses nearly all the predictors.

The R squared, RMSE, Theil's inequality coefficient, and $MAPE$ were used to evaluate the performance criteria of the prediction accuracy of the regression methods. As shown in Table 2, South Africa, Nigeria, and Tanzania recorded R squared of 10%, 45%, and 24% respectively, while Mozambique, Cote d'Ivoire, and DR Congo recorded R squared of 56%, 61%, and 71% respectively. Additionally, the results indicate that the Elastic Net model under the $minM$ rule yielded the smallest error value across $RMSE$, Theil's inequality coefficient, and $MAPE$ terms. Therefore, the Elastic NET method selects decomposition components that have more significant effect on the response variables with high prediction accuracy.

Table 2. Empirical Results of the Effect of Government Intervention on Income Inequality

Independent Variables	Dependent Variable: GINI					
	Nigeria	South Africa	Tanzania	Mozambique	DR Congo	Cote d'Ivoire
AGRIC	-0.158	0.000	-0.078	1.690	0.039	-0.982
	(0.000)	(0.000)	(0.000)	(0.311)	(-0.026)	(0.000)
EDU	-0.244	-2.166	0.274	1.496	0.016	-0.409
	(0.000)	(0.000)	(0.000)	(-0.071)	(0.000)	(0.000)
HEAL	-10.855	0.000	0.284	12.134	4.302	-14.833
	(0.000)	(0.000)	(0.000)	(-0.334)	(1.174)	(0.000)
SOCIAL	-0.244	-0.016	0.014	5.783	0.111	0.302
	(0.000)	(0.000)	(0.000)	(0.240)	(0.040)	(0.000)
TRANS	0.054	-0.089	-0.060	0.908	0.088	-0.230
	(-0.065)	(0.000)	(0.000)	(0.030)	(0.049)	(-0.065)
C	44.252	73.348	35.860	-1.213	37.606	42.105
	(40.239)	(60.119)	(36.996)	(48.849)	(39.605)	(40.239)
d.f.	5	3	5	5	5	5
L1 Norm	55.806	75.619	36.570	23.224	42.162	58.861
R-squared	0.451	0.097	0.238	0.558	0.712	0.607
RMSE	4.172	4.813	1.631	2.560	1.473	1.227
MAE	3.505	2.873	1.109	1.895	0.747	0.908
MAPE	8.172	5.572	3.019	3.913	1.737	2.291
Theils	0.050	0.040	0.022	0.026	0.018	0.015

Note: minimum optimal tuning values were reported and one standard error reported in ()
Source: Author's Calculations

From Table 2, unlike in Ghana (as shown in Appendix 3), the relationship between education expenditure and income inequality yielded negative coefficients in Nigeria, South Africa, and Cote d'Ivoire, respectively. This means that when education expenditure increases by 1%, income inequality decreases by a margin of 0.2%, 0.41%, and 2.17% in Nigeria, South Africa, and Cote d'Ivoire, respectively. This implies that increase in education expenditure helps to reduce the income inequality gap. This confirms economic theory, which states that education reduces income inequality. A study by Leibbrandt et al. (2011) in South Africa identified wage inequality as the main contributor to growing income inequality. However, education expenditure makes access to education available to all, which ultimately improves skills and, consequently, increases wages. This helps close the wage inequality gap, thereby reducing income inequality. Sanogo (2019) found similar results in Cote d'Ivoire. Contrary to this study's findings in DR Congo, World Bank (2018) found that government policy which enables an additional year of schooling is associated with a decline in the unemployment rate among men and women and increases the chance of obtaining wage employment in DR Congo. This consequently reduces wage inequality, which translates into a reduction in income inequality, as found in Nigeria, South Africa, and Cote d'Ivoire. Most studies find a negative relationship between income inequality

and a country's average or median educational attainment (Ospina, 2010; Sylwester, 2002; Anderson et al., 2017). On the other hand, the relationship between education expenditure and income inequality was positive in Tanzania, DR Congo, and Mozambique, as it was in Ghana (results in Chapter 1), contrary to economic theory. This indicates that when education expenditure increases by 1%, income inequality increases by a margin of 0.24%, 1.5%, and 0.02% in Tanzania, Mozambique, and DR Congo respectively. This indicates that education policies in Ghana, Tanzania, Mozambique, and DR Congo rather exacerbate the inequality gap. Heltberg et al. (2004), in explaining why education expenditure increases income inequality, indicated that there are inequalities in public spending at all levels of education and across regions in Mozambique. Hence, income inequality results from disparities in educational spending across regions. This is also the case in Ghana. There is evidence that educational inequality contributes to both intra-urban and rural-urban inequality (UNDP, 2017). Joumard and Vélez (2013) found similar results.

Health expenditure has no impact on income inequality in Nigeria and South Africa. This implies that, statistically, based on the results, health expenditure does not influence income inequality in Nigeria and South Africa. In Cote d'Ivoire, health expenditure has a negative impact on income inequality. This means that each 1% increase in health expenditure will consequently reduce income inequality by 14.83% in Cote d'Ivoire. These results confirm the findings in Cote d'Ivoire. Barofsky and Younger (2019) found that health expenditure significantly lowers income inequality in Ghana, as demonstrated by the aggregate-returns method, which also takes into account the value of prevented death and risk protection, even though the results in Appendix 3 indicated otherwise for Ghana. On the contrary, health expenditure has a positive impact on income inequality in Tanzania, Mozambique, and DR Congo, similar to the case of Ghana (see results in Appendix 3). This means that each 1% increase in health expenditure will consequently lead to a rise in income inequality by 0.28%, 12.13%, and 4.30% in Tanzania, Mozambique, and DR Congo, respectively. This result is in contrast with the two-period overlapping generation's growth theoretical model, which predicts an inverse relationship between health investment and income inequality. While Heltberg et al. (2004) blame the problem on imbalanced distribution across regions in Mozambique, the World Bank (2018) attributes the issue to low-quality health infrastructure and services provided at a higher cost in DR Congo, as well as many other African countries, including Ghana. Martinez-Vazquez et al. (2012) and Anderson et al. (2017) also found no relationship between health expenditure and income inequality, just as in the case of Nigeria and South Africa.

In addition, social protection expenditure has a positive impact on income inequality in Cote d'Ivoire, Tanzania, Mozambique, and DR Congo, contrary to the results found in Ghana and the predictions of economic theory. According to the results, income inequality will rise by 0.30%, 0.01%, 5.78%, and 0.11% when social protection expenditure increases by 1% in Cote D'Ivoire, Tanzania, Mozambique, and DR Congo, respectively. The World Bank (2018) found that investment in the provision of good quality social services remains abysmally low, resulting in a significant impact on income inequality in DR Congo. The findings of Sanogo (2019) in Cote d'Ivoire indicated that public investment to reduce inequality is more effective through education than through social services. He contends that only when social transfers are broken down into different sources does a particular source show a negative impact on income inequality; otherwise, social transfers do not have a negative impact on income inequality. However, as in Ghana (see results in Appendix 3), social protection expenditure has a negative impact on income inequality in South Africa and Nigeria, consistent with economic theory. When social protection expenditure increases by 1%, income inequality will reduce by 0.02% and 0.24% in South Africa and Nigeria, respectively. This implies that social protection expenditure reduces the income inequality gap in Nigeria and South Africa. De la Fuente et al. (2017), in their study, also suggested that a more efficient way to deliver net benefits to poor and vulnerable households is through targeted cash transfers. After Apartheid, South Africa further developed its social assistance pillars, such as the provision of basic resources to those unable to work due to age (Old Age Pension), disability (Disability Grant), or the need for supplementary income to support children (Child Support Grant). These measures have helped reduce the income inequality gap in the country (Leibbrandt et al., 2011). Martinez-Vazquez et al. (2012) and Anderson et al. (2017) also found similar results.

Interestingly, while agriculture expenditure has no impact on income inequality in South Africa, it has a positive impact in Nigeria, Mozambique, and DR Congo. Similarly, agriculture expenditure has a positive impact on income inequality in Ghana (see results in Appendix 3). When agriculture expenditure increases by 1%, income inequality rises by 0.19%, 1.69%, and 0.04% in Nigeria, Mozambique, and DR Congo, respectively, contrary to economic theory prediction. This may be because increasing investment in an Agrarian economy, where the majority are employed, raises their employment income, which should close the income gap, but apparently does not. Anyiam et al. (2023) found similar results in Nigeria, Mozambique, and DR Congo, and asserted that income inequality among high income farmers was greater than among low-income farmers, indicating that the respondents do not operate at the same level and do not earn the same income in Nigeria. Similarly, Al-Hassan and Jatoe (2003) studied the role of agriculture in

poverty reduction and found that investment in Ghana's agricultural sector led to disparities in incomes between export crop farmers and food crop farmers. This contrasts the findings of Horlu (2024), who demonstrated that increasing investment in crop diversities leads to a decrease in income inequality. Silva (2013) explained the situation in Mozambique, stating that agrarian policies following the post-1980s economic reform emphasized agricultural exports via policies such as agricultural extension programs that targeted export-producing farmers. However, these policies neglected the chronic shortages of farming inputs in rural areas and overlooked the rural population's dependence on wage labour to achieve food security. This ultimately led to increased income inequality in the country. On the other hand, agriculture expenditure has a negative impact on income inequality in Cote d'Ivoire and Tanzania. A 1% in agricultural expenditure reduces income inequality by 0.98% in Cote d'Ivoire and 0.08% in Tanzania. In DR Congo, Neema Ciza et al. (2022) found that increasing agricultural production boosts farm income, food supply, and job opportunities while also reducing income inequality.

Finally, transportation expenditure has a positive impact on income inequality in Nigeria, Mozambique, and DR Congo, but a negative impact in Cote d'Ivoire, South Africa, and Tanzania, similar to the results found in Ghana (see results in Appendix 3). When transport expenditure increases by 1%, income inequality increases by 0.91%, 0.05%, and 0.09% in Mozambique, Nigeria, and DR Congo, respectively. According to economic theory, government transport expenditure increases income inequality in the short run but decreases it in the long run, as it reduces transport poverty and enhances economic opportunities for the marginalized. Arndt et al. (2012), on the other hand, asserted that transport systems rather worsen the inequality gap in Mozambique, confirming this study's findings. Conversely, when transport expenditure increases by 1%, income inequality decreases by 0.23%, 0.09%, and 0.06% in Cote d'Ivoire, South Africa, and Tanzania, respectively. This is because improvements in transport infrastructure can enhance firm efficiency and affect firm location, thereby providing job opportunities to a broader population. Booth, Hanmer, and Lovell (2000), in their World Bank report, indicated the potential impact of transport expenditure in closing the income inequality gap in Nigeria and Madagascar, contrary to the findings in Nigeria. This finding is also in contrast to Calderón and Servén (2008), who claimed that transport expenditure is negatively correlated with income inequality.

The Estimate of the Benchmark Model of the Impact on Poverty

Table 3 presents the results of the impact of government expenditures used to implement various policy interventions on poverty across the six countries. Figure 3 shows the trace plot of the model, indicating that it is more suitable for out-of-sample prediction.

Figure 3. Elastic Net Trace Plot with Poverty as Dependent Variable
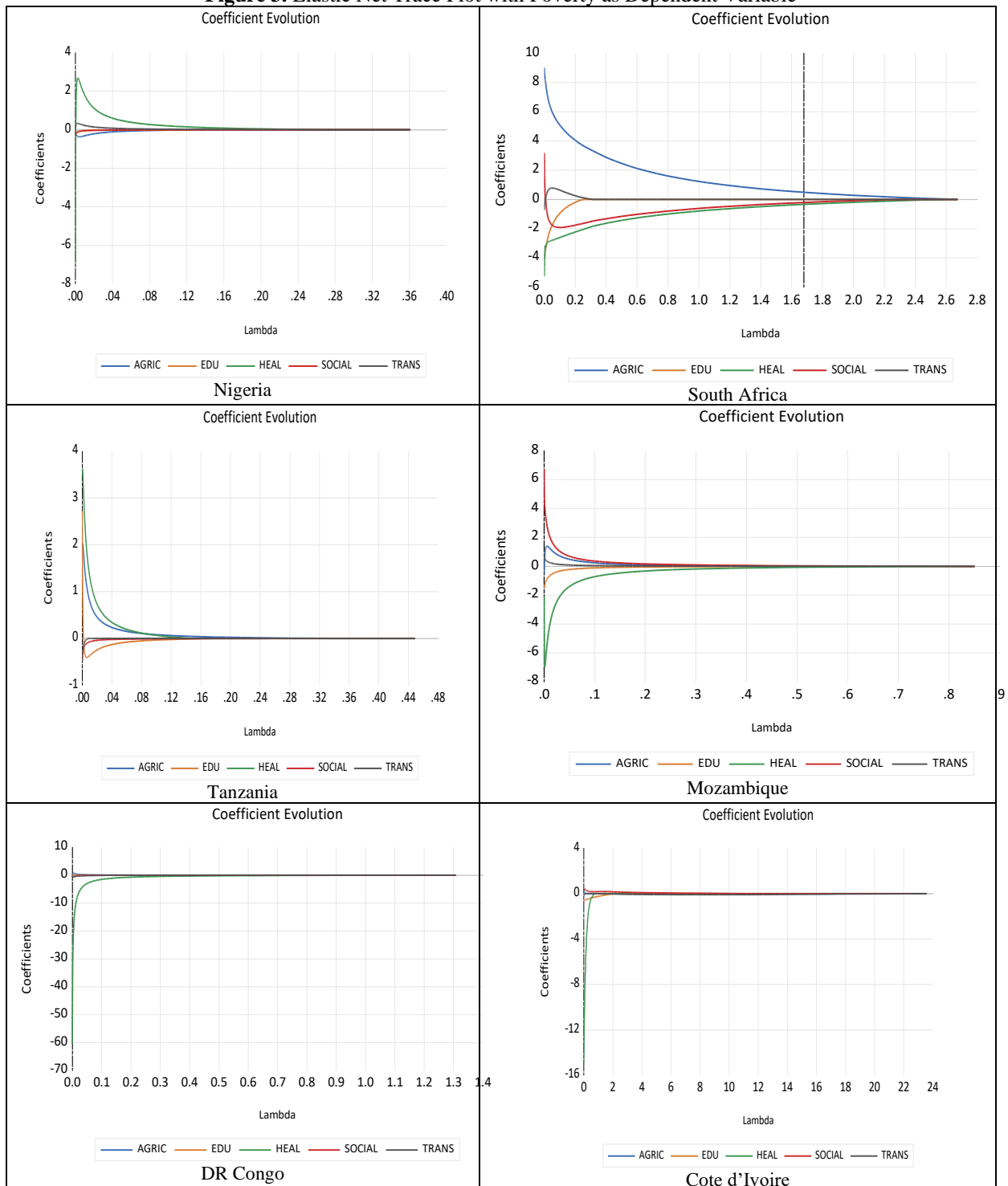
Source: Author's Calculation

The usual validation statistics are reported in Table 3: R squared is 78% for Nigeria, 85% for South Africa, 78% for Tanzania, 99% for Mozambique, 94% for DR Congo, and 47% for Cote d'Ivoire. The results also show that the Elastic Net method, under the $minM$ rule has the smallest error value in the terms of $RMSE$, Theil's inequality coefficient, and $MAPE$. Therefore, the Elastic NET method selects decomposition components that have a more significant effect on the response variables, while achieving high predictive accuracy.

Table 3. Empirical Results of the effect of Government Intervention on Poverty

Independent Variables	Dependent Variable: POV					
	Nigeria	South Africa	Tanzania	Mozambique	DR Congo	Cote D'Ivoire
AGRIC	-0.277	0.486	1.788	-0.548	0.123	0.361
	(-0.214)	(0.486)	(2.008)	(0.076)	(0.766)	(0.000)
EDU	-0.282	0.000	2.723	-1.283	0.047	-0.610
	(-0.236)	(0.000)	(0.565)	(-1.434)	(0.080)	(0.000)
HEAL	-6.886	-0.339	3.518	-2.060	-49.172	-14.851
	(-0.356)	(-0.339)	(3.489)	(-6.202)	(-23.103)	(0.000)
SOCIAL	-0.319	-0.213	-0.485	6.737	-0.514	0.395
	(-0.200)	(-0.213)	(-0.289)	(4.933)	(-0.599)	(0.000)
TRANS	0.065	0.000	-0.499	0.816	-0.470	-0.205
	(0.218)	(0.000)	((-0.268)	(0.603)	(-0.701)	(0.000)
C	16.112	21.718	56.075	14.094	83.975	7.779
	(11.771)	(21.718)	(61.486)	(28.693)	(82.783)	(8.885)
d.f.	5	3	5	5	5	5
L1 Norm	23.942	22.756	65.088	25.537	134.301	24.202
R-squared	0.782	0.847	0.777	0.985	0.935	0.467
RMSE	3.103	1.698	3.855	1.498	4.875	1.995
MAE	2.598	1.255	2.941	1.111	3.745	1.391
MAPE	14.119	14.746	4.181	2.934	7.461	27.724
Theil's	0.080	0.076	0.027	0.017	0.036	0.109

Note: minimum optimal tuning values were reported and one standard error reported in ()
Source: Author's Calculations

The results in Table 3 show that, except for Mozambique and the case of Ghana (see results in Appendix 3), there is a positive relationship between agriculture expenditure and poverty in Cote d'Ivoire, South Africa, Nigeria, Tanzania, and DR Congo. This does not align with economic theory expectations, as agricultural expenditure was expected to reduce poverty. According to the results, when agriculture expenditure increases by 1%, poverty increases by a margin of 0.36%, 0.49%, 0.16%, 1.79%, and 0.12% in Cote d'Ivoire, South Africa, Nigeria, Tanzania and DR Congo, respectively. The largest reserve of arable land in Africa, with favourable climate and abundant water throughout the year, is found in DR Congo. Ofori-Boateng and Bab (2015) claim that poverty is primarily an agricultural phenomenon in most parts of Africa, including Ghana, and is largely concentrated in the informal

sector. It is therefore surprising that agricultural expenditure contributes to more poverty in this country. The situation in Cote d'Ivoire has been attributed to trade and policy control that favoured imported goods over exported goods in the agricultural sector (Kone, 2007).

To explain, the World Bank (2018) suggests that urgent reforms should be implemented due to the intertwined factors, in order to create an enabling environment in the agricultural sector to achieve poverty reduction. It is quite difficult for a farmer to escape poverty because agriculture produces relatively little revenue (Neema Ciza et al., 2022). Therefore, it is critical to address the issue of farming household incomes and target low incomes from all sources of income by establishing an equitable and effective anti-poverty programme in rural areas. Anyiam et al. (2023) found contrary results for Nigeria. Agriculture expenditure has a negative impact on poverty in Mozambique. When agriculture expenditure increases by 1%, poverty decreases by 0.55% in Mozambique. Silva (2013) asserted that a number of variables that previously required the state to use force have been changed, encouraging smallholders to participate in market-based agriculture. The production of agricultural crops and livestock provided income for many households, highlighting the significance of the farm economy in rural Mozambique, thus contributing to the reduction in poverty. Al-Hassan and Jatoe (2003) conducted a study in Ghana and showed that the country's poorest groups, who are food crop farmers, have seen the least improvement in their levels of poverty since 1991. They suggested that strategies and policies encouraging the production of farm non-tradables are most likely to have the biggest impact on growth and the reduction of poverty. Horlu (2024) made similar remarks in his study in Ghana. Furthermore, the relationship between education expenditure and poverty yielded negative coefficients in Cote d'Ivoire, Nigeria, and Mozambique, in line with economic theory. This implies that increases in education expenditure help to reduce poverty. Contrary to the findings, policies targeted at improving educational attainment in DR Congo among household members had a negative impact on poverty (World Bank Group, 2018). Abaidoo (2021) used probit and logit models and two-stage least square estimation and found that, contrary to the results in Appendix 3, education has a significant negative relationship with poverty in Ghana. Similar findings were reported in Mozambique by Da Maia (2012). Joumard and Vélez (2013) also found a negative relationship between education expenditure and poverty. While there is no relationship between education expenditure and poverty in South Africa, there is a positive relationship between education expenditure and poverty in Tanzania and DR Congo. This means that when education expenditure increases by 1%, poverty increases by 2.72% and 0.05% in Tanzania and DR Congo, respectively. Ibale, Docquier, and Iftikhar (2024) posit that policies targeting education and public

infrastructure have smaller effects due to the low mobility of unskilled workers across sectors, thus primarily impacting productivity in the formal sector and leaving the majority impoverished. In South Africa, there is evidence that students' abilities have declined rather than improved, with academic achievements showing significant inequality compared to international standards (Leibbrandt, Finn, & Woolard, 2010). These findings imply that increased spending has not translated into better educational quality or reduced poverty (Leibbrandt, Finn, & Woolard, 2010).

In addition, except for Tanzania, health expenditure has a negative impact on poverty in Cote d'Ivoire, Nigeria, South Africa, DR Congo, and Mozambique. This result aligns with economic theory. Specifically, a 1% increase in health expenditure leads to a reduction in poverty by 14.85%, 0.09%, 0.34%, 49.17%, and 2.06% in Cote d'Ivoire, Nigeria, South Africa, DR Congo, and Mozambique, respectively. These findings are consistent with the results in Ghana (see Appendix 3). The rationale is that government spending in the health sector reduces individuals' out-of-pocket health expenses, thereby lowering poverty levels. Heltberg et al. (2004) suggested that the decline in poverty due to public spending on healthcare and other sectors was influenced by the HIPC initiative, which many African countries adopted. In contrast, in Tanzania, a 1% increase in health expenditure results in a 3.52% in poverty. Martinez-Vazquez et al. (2012) and Anderson et al. (2017) reported similar findings in the case of Tanzania. In Ghana, Adjei-Mantey and Horioka (2023) showed that the availability of health facilities within one's community significantly reduces health care expenditures, thereby alleviating poverty - corroborating the findings in this article.

Furthermore, social protection expenditure has a positive impact on poverty in Cote d'Ivoire, Tanzania, and Mozambique, similar to the findings in Ghana (see results in Appendix 3). According to the results, when social protection expenditure increases by 1%, poverty rises by 0.40%, 0.49%, and 6.74% in Cote d'Ivoire, Tanzania, and Mozambique, respectively. Lucky and Sam (2018) confirmed this finding in Nigeria and concluded that social insurance policies, such as unemployment and pension insurance, tend to be more regressive than progressive. In contrast, Hodges et al. (2013) indicated that cash transfers reduce monetary poverty in Cote d'Ivoire and the Democratic Republic of Congo. Sackey (2019) explained the situation in Ghana by arguing that social protection programmes, such as the LEAP programme, are plagued by deficiencies in the amount of cash disbursed and challenges in accessing free services. Honorati (2015) also asserted that, although Ghana has many social assistance, social insurance, and labour market programmes, the system's reach remains limited, particularly for the country's poor. It is therefore not surprising that social protection programmes may inadvertently increase poverty in Ghana. Similar challenges are also

faced in other African countries, such as Cote d'Ivoire and Tanzania. On the other hand, social protection expenditure has a negative impact on poverty in Nigeria, South Africa, and DR Congo. When social protection expenditure increases by 1%, poverty decreases by 0.09%, 0.21%, and 0.51% in Nigeria, South Africa, and DR Congo, respectively. This implies that social protection expenditure reduces poverty, which aligns with economic theory. Martinez-Vazquez et al. (2012) and Anderson et al. (2017) reported similar findings for Cote d'Ivoire, Tanzania, and Mozambique. The case of South Africa is not surprising. According to a UNDP (2017) report, despite the establishment of social protections across the board (except in Southern Africa, Ethiopia, and a few other nations), there was slowdown in progressive redistributions and in the number of transfer programmes implemented due to a lack of fiscal space.

Finally, transportation expenditure has a negative impact on poverty in Cote d'Ivoire, Nigeria, Tanzania, and DR Congo, unlike in Ghana (see results in Appendix 3), which aligns with economic theory. From Table 3, when transport expenditure increases by 1%, poverty decreases by 0.21%, 0.09%, 0.5%, and 0.47% in Cote d'Ivoire, Nigeria, Tanzania, and DR Congo, respectively. Government policies that promote free public transportation and reduce reliance on private vehicle use help citizens save more and alleviate travel-related poverty. According to Booth, Hanmer, and Lovell (2000), improving access to transport services, increasing ownership of means of transport, and upgrading infrastructure most used by the poor are all essential to reducing poverty. However, while transportation expenditure has no significant impact on poverty in South Africa, it has a positive impact in Mozambique. A 1% increase in transport expenditure results in a 0.82% increase in poverty in Mozambique. According to the World Bank (2018), poor transport performance, which affects mobility and accessibility in both urban and rural areas, hinders business activities and is a key contributor to persistent poverty in Africa. Sutherland and Kerr (2021) also found no significant impact of transport expenditure on poverty in post-apartheid South Africa, which aligns with the findings of this study. The results from Cote d'Ivoire, Nigeria, Tanzania, and DR Congo are consistent with those of Calderón and Servén (2008). As showed by Arndt et al. (2012), trade and transport systems are among the most severe structural constraints to poverty reduction in Mozambique. In Nigeria, Oladipo and Olomola (2016) found a negative relationship between transport expenditure and poverty, while Osundina et al. (2014) reported contrary findings.

Conclusion

This paper examined the extent to which government-implemented policies have contributed to reducing poverty and income inequality in six African countries - Nigeria, South Africa, Mozambique, Cote d'Ivoire, DR

Congo and Tanzania - compared to Ghana. The Elastic Net Regression, a machine learning technique, was employed to estimate the baseline model.

The main findings revealed that, unlike Ghana, education expenditure had a negative relationship with income inequality in Nigeria, South Africa, and Cote d'Ivoire, but a positive relationship in Tanzania, DR Congo, and Mozambique. Regarding its impact on poverty, education expenditure showed a negative relationship in Cote d'Ivoire, Nigeria, and Mozambique, but a positive relationship in Tanzania and DR Congo consistent with the findings for Ghana.

In Cote d'Ivoire, health expenditure had a negative impact on income inequality. In contrast, it had a positive impact in Tanzania, Mozambique, and DR Congo, similar to Ghana. Except for Tanzania, health expenditure had a negative effect on poverty in Cote d'Ivoire, Nigeria, South Africa, DR Congo, and Mozambique - once again, consistent with Ghana.

Furthermore, social protection expenditure reduced income inequality in South Africa and Nigeria, as it did in Ghana. However, in Cote d'Ivoire, Tanzania, Mozambique, and DR Congo, it had the opposite effect. Regarding poverty, social protection expenditure had a positive impact in Cote d'Ivoire, Tanzania, and Mozambique, as in Ghana, but a negative impact in Nigeria, South Africa, and DR Congo.

Interestingly, agriculture expenditure increased income inequality in Nigeria, Mozambique, and DR Congo, similar to Ghana, but had a reducing effect in Cote d'Ivoire and Tanzania. Regarding poverty, agriculture expenditure showed a positive relationship in Cote d'Ivoire, South Africa, Nigeria, Tanzania, and DR Congo, but a negative relationship in Mozambique, consistent with Ghana.

Finally, transportation expenditure increased income inequality in Nigeria, Mozambique, and DR Congo, but reduced it in Cote d'Ivoire, South Africa, and Tanzania - similar to Ghana. In terms of poverty, transportation expenditure had a negative effect in Cote d'Ivoire, Nigeria, Tanzania, and DR Congo, whereas in Mozambique, it had a positive impact, in line with Ghana's results.

The main policy implications are as follows:
   i.   Policies that reduce poverty do not always lead to reductions in income inequality;
  ii.   Each policy has a unique and country-specific impact on both income inequality and poverty;
 iii.   To reverse the current trends of diverging inequality, each country must implement complementary policies that simultaneously address both poverty and income inequality.

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Appendix 1: ADF Unit Root Tests Results for Variables under Study

VARIABLES	Nigeria	Cote D'Ivoire	South Africa	Tanzania	Mozambique	DR Congo
AGRIC	-11.616	-5.415	-4.217	-4.700	-10.848	-4.925
EDU	-5.433	-4.252	-4.774	-5.212	-6.310	-5.493
HEAL	-6.972	-8.564	-7.485	-6.008	-6.925	-4.209
SOCIAL	-5.073	-5.867	-6.381	-7.545	-4.847	-6.533
TRANS	-7.643	-27.739	-5.025	-5.723	-0.048	-4.906
TAXREV	-4.884	-6.137	-5.580	-5.583	-3.176	-24.871
POV	-5.041	-6.130	-5.249	-5.479	-7.365	-9.067
GINI	-6.512	-7.031	-2.241	-9.415	-5.857	1.940

NB: All coefficients are measured at first difference.

Appendix 2: Descriptive Statistics for the Variables (1987 – 2019)

DR Congo							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	-0.171	7.232	0.170	13.752	9.526	40.819	64.389
Maximum	1.904	19.117	0.662	26.552	16.445	51.200	96.030
Minimum	-2.631	0.815	-0.273	1.512	2.897	36.718	32.700
Std. Dev.	1.431	6.040	0.273	6.768	3.093	2.787	19.374
Observations	33	33	33	33	33	33	33
Mozambique							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	1.395	3.633	1.199	7.133	-13.709	49.925	43.065
Maximum	3.286	6.876	1.841	8.246	-4.609	54.000	63.217
Minimum	0.669	0.501	0.632	6.021	-22.809	39.900	22.913
Std. Dev.	0.509	1.955	0.361	0.672	5.499	3.911	12.271
Observations	33	33	33	33	33	33	33
Tanzania							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	1.500	3.363	1.563	4.536	2.906	36.996	69.764
Maximum	4.072	5.359	2.380	30.104	11.176	40.500	80.483
Minimum	-0.849	2.138	0.746	-21.032	-0.142	31.700	58.000
Std. Dev.	1.038	0.834	0.335	15.644	2.882	1.897	8.282
Observations	33	33	33	33	33	33	33
South Africa							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	1.453	5.134	2.770	52.090	14.438	60.119	10.392
Maximum	2.307	5.918	4.817	79.869	16.530	64.800	17.231
Minimum	0.871	4.352	0.564	26.229	9.245	34.600	3.552
Std. Dev.	0.536	0.459	1.341	15.790	1.232	5.144	4.408
Observations	33	33	33	33	33	33	33
Cote d'Ivoire							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	0.907	3.919	0.524	25.781	-3.753	40.481	8.885
Maximum	2.376	6.781	0.994	37.217	9.091	43.200	12.400
Minimum	0.458	2.400	0.142	14.345	-17.239	36.900	2.200
Std. Dev.	0.419	1.571	0.236	6.978	8.162	1.987	2.775
Observations	33	33	33	33	33	33	33
Nigeria							
	AGRIC	EDU	HEAL	SOCIAL	TRANS	GINI	POV
Mean	0.983	-12.951	0.813	-12.275	6.833	41.807	18.264
Maximum	4.213	0.6354	1.202	20.482	14.822	51.900	27.900
Minimum	-0.674	-30.553	0.446	-40.850	2.726	35.100	8.879
Std. Dev.	0.879	10.859	0.272	17.325	2.535	5.729	6.745
Observations	33	33	33	33	33	33	33

Appendix 3: Empirical results of the effect of Government Intervention on Income Inequality and Poverty in Ghana

	(minimum)	(+ 1 SE)	(minimum)	(+ 1 SE)
Lambda	0.0001385	0.002984	0.0005502	0.002221
Variable	INCOME INEQUALITY			POVERTY
AGRIC	0.783	0.428	-0.171	-0.137
EDU	0.185	0.192	0.756	0.229
HEAL	3.032	1.393	-7.610	-4.630
SOCIAL	-0.008	-0.001	0.030	0.014
TRANS	-0.177	-0.203	0.914	0.648
C	35.304	37.440	21.662	21.502
d.f.	5	5	5	5
L1 Norm	39.490	39.656	31.143	27.161
R-squared	0.638	0.496	0.612	0.471
RMSE	1.457		3.733	
MAE	1.173		2.937	
MAPE	2.923		22.189	
Theils	0.018		0.100	

Debt versus Equity in Corporate Financing: Distinction and Resemblance Between Agency Theory and Market Timing Theory in Capital Structure Decisions

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Abstract

This study examines the preference for debt over equity issuance among U.S. companies and analyzes the financial and structural implications of financing decisions by focusing on the interplay between agency theory and market timing theory. The research investigates how these theories explain financing preferences, assesses the impact of key financial ratios on debt levels, and explores the implications for corporate financial strategies. The research employed a quantitative panel data regression analysis, utilized secondary data from 64 U.S. companies over quarterly periods between 2012 and 2017, and sourced from the Securities and Exchange Commission (SEC). Analytical techniques include the Mahalanobis Distance for outlier detection, Pearson's correlation matrix for multicollinearity assessment, and Hausman and Lagrange multiplier tests were used to validate the fixed-effects model.

Findings reveal that companies tend to issue debt to reduce their tax liabilities and increase post-tax cash flow available for dividends. However, a negative relationship is observed between liquidity, measured by the current ratio (CR), and the debt ratio, suggesting that higher liquidity levels lead companies to limited debt, potentially to mitigate agency costs between creditors, management, and owners. Additionally, the negative relationship between company size and debt ratio indicates that larger companies, with higher profitability, tend to maintain lower debt levels. Conversely, asset utilization shows a positive relationship with debt, indicating efficient asset

use supports higher borrowing capacity. Notably, share price performance and tangibility were statistically insignificant, implying that market timing has limited influence on debt decisions.

The findings highlight the complex dynamics of capital structure decisions, which emphasize the importance of aligning management incentives to maximize shareholders' value while minimizing agency costs. This alignment process would be achieved through performance-based compensation, which is tied to liquidity optimization, profitability, growth opportunities and stock price performance. The study provides a comprehensive evaluation of how equity and debt financing preferences impact corporate financial strategies and behaviors. The study highlights the benefits from tax advantages of debt financing, which enhances post-tax cash flow. The research contributes to the broader understanding of corporate financing strategies in developed markets, though further studies could explore cross-market comparisons.

Keywords: Agency Theory, Market Timing Theory, Current Ratio, Tangibility, Share Price Performance

Introduction

Equity is a company's book value. Besides, equity is the amount of money that is credited to the company's owners and should be returned to the owners in case all assets are liquidated. On the other hand, Equity, as a financing resource, is the debt that is credited to the company's owners as a loan. Accordingly, there are two types of equity financing resources: internal and external equity. Internal equity is considered when a company decides, for example, to finance its assets from either retained earnings or depreciation, while the external equity financing resource is considered when a company decides to issue new equity shares. On the other hand, Debt is the amount of money that is credited to a second party other than the company's owners. Generally, there are two types of debts: short-term debt and long-term debt. Generally, short-term debt is utilized to finance daily operational expenses, while long-term debt is utilized to finance growth opportunities. Through previous definitions of financing resources, equity and debt, companies need to make a financing decision that leads to owners' maximum wealth. A good capital structure decision is needed when a company decides to finance its assets in order to increase its wealth through investment and growth opportunities (Chung et al., 2013), to finance the pay to dividends, to finance its working capital, or to finance the compensation of cash flow due to deficit (Frank and Goyal, 2003) or due to poor business performance (Chung et al., 2013) or due to volatility. The good capital structure decision results from analyzing financial ratios known as capital structure determinants in order to

produce the optimum proportions of these determinants which produce and maintain the optimum debt ratio (Youssef and El-ghonamie, 2015; Nasimi, 2016) that maximize the owners' wealth.

In line with this context, this research explores some determinants of the capital structure that have been included in several previous journals and confirms the results with two well-known theories: agency theory and market timing theory. In other words, this research aims to provide evidence of how both agency theory and market timing theory explain the companies' financing decisions by interpreting the effect of their capital structure decisions. In addition, aims that its findings may have important implications for companies in terms of simplifying the applications of these theories. The research aims to find if there is any correlation or interaction in the decision-making process between agency theory and market timing theory in terms of financing decisions. Therefore, the main questions of the research are; when a company seeks cash, is the financing decision affected more by agency costs or by market conditions? And if the market conditions tend to be suitable for issuing new debt, does the theory of agency cost help in deciding whether the company goes for internal equity for financing, or might go for external equity and issue new shares?

The result of this research implies that the independent variables can be considered as determinants of the capital structure of U.S. corporations. In addition, the results of this research are consistent with some financial theories. The research showed that companies do not fully follow the agency theory and nor do the market timing theory. The research's main findings were that when a company experiences a high current ratio, they have a lower debt ratio and thus larger companies tend to issue more equity than debt. This means that the financing decisions often depend on the amount of debt accessible, regardless of the management performance and the efficiency of asset utilization. The current ratio (CR) was found statistically significantly negative with the debt ratio, the financial performance or profitability (FP) was found statistically significantly negative with the debt ratio, and asset utilization (AU) was found significantly positive with the debt ratio, and the company's size was found statistically significantly negative with debt ratio. On the other hand, asset structure or tangibility (AS) and share price performance were found statistically insignificantly positive with the debt ratio.

The research has been designed in a way to investigate how the agency theory and market timing theory interpret companies' problems and how they conform to solving principles as suggested by these theories. The research includes five parts: Introduction, Literature Review, Methodology, Data and Results, and Conclusion and Discussion. The literature review includes many journals that have been carefully reviewed and analyzed. Since the statistical

method and methodology relied on the literature review, it was ensured that the methodology was complemented with all journals that have been reviewed. In the data and results part, all variables introduced in this research have been fully interpreted in order to provide statistically convincing evidence that is consistent with the capital structure theories. The conclusion and discussion part summarizes all variables and their results and interpretations.

Literature Review

Finding the optimal mix of debt and equity is the most interesting topic in corporate finance because an incorrect financial decision may disrupt any company's fortunes and have the tendency to stall the fortunes of any business. Therefore, the management financing decision should be taken in the right direction, debt and/or equity, and at the right time to achieve and identify the optimal financing mix. Therefore, the optimum debt ratio is a critical strategic decision (Modugu, 2013) that is identified by the company's determinants (Harmono, 2017). These determinants' impact on the debt ratio should be identified (Leland, 1994; Karadeniz et al., 2011; Palacim-Sanchez et al., 2013). Equity and debt are located on the liability side of the balance sheet (Myers, 2001) and form a company's capital structure (Acaravci, 2015). Determining the best capital structure is needed to maintain and maximize a company's profitability, survival, growth, and value (Eriotis et al., 2007). The capital structure decision refers to the options that a company uses to finance its assets and thus its investments (Modugu, 2013). These options usually range from full debt to full equity or a mix between them. There is no universal theory of optimal debt-to-equity level (Myers, 2001), but there are several theories, as identified earlier, that can be used to interpret the debt-to-equity ratio that a company chooses.

Agency Theory

Agency theory occurs because the management may pursue their goals and benefits more than the owners' goals and benefits (Kim and Gu, 2005). On the other hand, the agency theory assumes that the conflict of interests and information asymmetry can be reduced by controlling the free cash flow that is required to offset the under-estimated investments and asset issues (Cotei and Farhat, 2009). The agency costs, which are explained by the agency theory, emerged from the conflict between the company's top management and ownership as a result of information inconsistency and asymmetry. According to Kim and Gu (2005), Compensation is related to managerial performance and is better, easier, and sometimes cheaper than monitoring performance. Therefore, the agency theory focuses on the oversight issues resulting from the problem of harmonization of the interests of agents or

management and shareholders. These types of conflicts of interest can be resolved through both the compensation and monitoring mechanisms structure. These monitoring and controlling costs constitute what is known as agency costs. According to Acaravci, (2015), these costs are spent by owners to ensure managers' efficiency and to reduce the conflict of interests' level in terms of goals and objectives between owners and managers.

The agency costs, which are explained by the agency theory, can be minimized by utilizing compensation for performance. According to Kim and Gu (2005), Compensation is related to managerial performance and is better, easier, and sometimes cheaper than monitoring performance. In addition, they suggested that compensation based on performance is a solution that can be applied to solve the agency problem in order to align the interests of shareholders with management. Therefore, the compensation should be designed to motivate and retain management talent to meet shareholders' expectations while maintaining that the agency costs are not raised significantly. On the other hand, the agency theory assumes that the conflict of interests and information asymmetry can be reduced by controlling the free cash flow that is required to offset the under-estimated investments and asset issues (Cotei and Farhat, 2009). Therefore, the other strategy that is used to reduce the free cash flow and agency costs level is by using debt that consumes the free cash flow and transfers the monitoring of investment risk to the creditors. This strategy helps owners to monitor company performance and reduce the possibility of having an underestimated investment.

Since the agency theory is based on the premise that managers do not perform their duties in the best interest of the owners, this definition can be more elaborated by imposing, firstly, a conflict of interest between owners and management, and secondly between owners and debt creditors (Berger and Patti, 2006; Acaravci, 2015). The conflicts of interest between owners and managers arise as a result of the possibility that managers may seek profits from the company they manage for personal gain at the expense of the owners. The conflicts of interest between the owners and debt creditors arise as a result of the possibility that debt may mitigate the optimal investment incentives. If the return on the investment is higher than the nominal value of the debt, the benefits are to the owners. Conversely, if the investment loss or the return of the investment is lower than the nominal value of the debt, or the company is near to announcing its bankruptcy, the owners have limited responsibility and thus low liability by using their rights to stay away and leaving the debt creditors with a company with a market value below the nominal value of outstanding debt. This means that debt has both positive and negative impacts on owners. The positive impact is that the debt reduces ill-considered investments. The negative impact is that too much debt can lead to high-interest payments, which may lead to a reduction in the acceptance of

profitable investments and thus the under-investment problem occurs. Therefore, the agency theory demonstrates the agency costs through their impacts on a company's capital structure decisions. Furthermore, agency theory interprets agency costs by investigating several determinants such as growth, free cash flow, and management performance.

Compared with the trade-off theory, one assumption of the trade-off theory there is no agency cost; there is no dispute between management and owners. It assumes that managements always maximize owners' wealth. On the other hand, according to Alzomaia (2014), the trade-off theory argues that in the absence of taxes, the determinants of the capital structure of a company are irrelevant to its value. These assumptions and arguments are known as the irrelevancy theorem. Thus, the optimal capital structure of a company can be achieved through the efforts of all stakeholders, management, and owners in order to maximize the value and minimize total costs that are related to the company, or the agency. In other words, according to the agency theory, it is possible to achieve the optimal capital structure in a world without taxes or bankruptcy. According to Berger and Patti (2006), agency theory presumes that debt affects agency costs and thus affects company performance. They proposed a new method to interpret the agency theory by using profit efficiency, or how close the profit is to the optimum performance of a company that is facing the same external conditions. Furthermore, they employed a synchronous equations model that explains the inverse causality of a company's performance to its capital structure. They found that the United States baking industry is consistent and statistically significant with the agency theory and the proper choice of capital structure helps in mitigating the agency cost effects.

The agency theory assumes that all managerial actions are driven by self-interest, which oversimplifies human behavior. In addition, managers often exhibit intrinsic motivation and ethical considerations that are not accounted for in agency theory. In other words, agency theory focuses on monetary incentives, such as performance-based compensation, neglects non-financial motivators like job satisfaction and organizational culture, which can also align managerial and shareholder interests. Another limitation is the theory's narrow view of debt as a tool to mitigate agency costs. While debt can reduce free cash flow and limit managerial discretion, excessive debt can lead to financial distress and underinvestment, as highlighted by Berger and Patti (2006). Moreover, agency theory assumes a homogeneous group of shareholders with aligned interests, which is rarely the case in practice. Institutional investors, for example, may have different priorities than individual shareholders, leading to complex governance dynamics that agency theory fails to address (Bebchuk and Tallarita, 2020). The theory also overlooks the role of stakeholder capitalism, where companies balance the

interests of shareholders with those of employees, customers, and society which forms a growing trend in modern corporate governance.

Market Timing Theory

According to the trade-off theory, when a company looks for an external source of finance, it prefers to issue new equity over debt when the stock price is high or inflated even when the company either experiences a very low net present value over investments or does not achieve its capacity of debt (Myers, 1984). In other words, to time the market process is highly considered when a company decides to be financed by external financing resources. On the other hand, when the value of a company improves, the company offsets its equity by increasing debt (Myers, 1984). Furthermore, according to Allini et al. (2018), the order of the proposed financing selection by the pecking order theory changes over time. Huang and Ritter (2009) described the pecking order theory as a special case of the market timing theory, especially when the cost of issuing equity is more than the cost of debt. Unlike the pecking order theory, the market timing theory does not assume a low likelihood of issuing equity as the pecking order theory assumes because the pecking order theory highly considers semi-strong market efficiency as the major influencer on information asymmetry (Huang and Ritter, 2009). This means that the pecking order theory presumes a low probability impact of information asymmetry and thus it cannot clearly explain the chosen financing resource, either equity or debt when the stock price is high. The market timing theory does not propose an optimal level of capital structure (Baker and Wurgler, 2002) but it suggests that there is an opportunity that could be exploited as the cost of equity changes over time (Huang and Ritter, 2009). Therefore, companies should take advantage of the stock market change compared to the cost of either financing resources, equity, or debt (Baker and Wurgler, 2002). In other words, to time the market process is highly considered when a company decides to be financed by external financing resources.

The market timing theory explains and develops a relationship between equity market timing and companies' capital structure (Baker and Wurgler, 2002). The market timing theory better explains the changes in the cost of equity over a time cycle (Huang and Ritter, 2009). The market timing theory predicts that when companies issue new equity in an opportune market situation (Cotei and Farhat, 2009) and when the price-to-book value is high. When time passes during successive economic cycles is the main influence on determining the financing source (Feidakis and Rovollis, 2007). Zavertiaeva and Nechaeva (2017) argued that companies switch to a debt market timing approach during the crisis and recovery cycle due to the low availability of sufficient investors' liquidity. Therefore, the market timing theory better

explains the changes in the cost of equity over a time cycle (Huang and Ritter, 2009). This means that, when companies decide to go for external financing resources, companies should take advantage of the stock market change compared to the cost of either financing resources, equity, or debt (Baker and Wurgler, 2002). In other words, the attempt to time the market is an added determinant of capital structure (Chung et al., 2013) in order to add the market impacts and their inconsistency on this capital structure (Zavertiaeva and Nechaeva, 2017). The market timing theory predicts that when companies issue new equity in an opportune market situation (Cotei and Farhat, 2009) when the price-to-book value is high. On the other hand, companies increase debt when investment opportunities are plentiful and demand for venture capital is high or when they experience poor business performance that reduces their stock price or forces them to borrow (Chung et al., 2013). Therefore, the debt ratio will be reduced, as well as the financing deficit will be recovered, while the financing surplus will be increased (Cotei and Farhat, 2009). In other words, when the stock price is high, companies issue more equity, while when the stock price is low, they tend to purchase back their equity.

From the market timing perspective, the capital structure is a cumulative result of earlier market situations (Chung et al., 2013). According to Baker and Wurgler (2002), capital structure is the cumulative result of a manager's endeavor to time the capital market. Based on companies' behavior, Baker and Wurgler (2002) noted that there are two types of equity market timing. The first type is dynamic, which is affected by stories about companies' intention to issue new equity. The second type a company issues new equity when they experience a low cost of equity, while they repurchase equity when the cost of equity is high. According to Sinha and Ghosh (2009), the dynamic type of market timing affects the cost of information asymmetry in a short-term period. This effect may lead to a dynamic reverse of the order of financing source selection and thus companies may follow the pecking order selection process. On the other hand, in a long-term period, Sinha and Ghosh (2009) found that there is no dynamic reverse in the order of financing source of selection.

In terms of the theory approach, there are two types of market timing theory. In the first type, the theory presumes that companies' management is rational and thus companies issue new equity after the publication of positive information to reduce information asymmetrical problems. The publication of positive information leads to an increase in the share price and thus timing (Baker & Wurgler, 2002). Contrary, the second type presumes that the investors' irrational behavior may reduce the share price and thus companies repurchase their equity. In terms of the market timing approach, there are two types of market timing theory. The first type is when the companies issue new

equity at a high share price and repurchase it at a low share price, while the second type is when companies increase their debt at low interest costs (Zavertiaeva and Nechaeva, 2017). That is what Serghiescu and Văidean (2014) explained, the market timing theory determines some situations of the stock market and macroeconomics within a country that may affect the capital structure of companies listed on an exchange market list. Finally, the market timing theory does not propose an optimal level of capital structure (Baker and Wurgler, 2002), but it suggests that there is an opportunity that could be exploited as the cost of equity changes over time (Huang and Ritter, 2009).

The market timing theory assumes that managers can accurately time the market. Loughran and Ritter (2004) demonstrate that market timing is fraught with challenges, as stock prices are influenced by unpredictable economic factors and investor sentiment. Therefore, many companies that attempt to time the market end up issuing equity at inflated prices, only to face subsequent declines, leading to value destruction for shareholders. In addition, market timing theory lacks a coherent framework for explaining how firms balance the trade-offs between equity and debt financing over time. Unlike trade-off theory, which provides clear guidelines for optimizing capital structure based on tax benefits and bankruptcy costs, market timing theory offers no such guidance (Frank and Goyal, 2009). This makes it difficult for firms to apply the theory in practice, particularly in volatile market conditions.

Furthermore, market timing theory does not account for the long-term consequences of financing decisions. While issuing equity during high market valuations may provide short-term benefits, it can dilute ownership and reduce earnings per share, negatively impacting long-term shareholder value (Graham and Harvey, 2001). Similarly, increasing debt during low-interest periods may lead to unsustainable leverage levels, increasing the risk of financial distress during economic downturns. The theory also overlooks the role of information asymmetry in capital markets. Huang and Ritter (2009) argued that companies with high information asymmetry may struggle to time the market effectively, as investors may discount their equity offerings due to uncertainty. This contradicts the theory's implicit assumption that all firms have equal access to market timing opportunities.

Variables

This study's empirical strategy is informed by both agency theory and market timing theory. Agency theory suggests that conflicts of interest between managers and shareholders can influence capital structure decisions. To examine this, the study includes variables like the current ratio, financial performance, asset utilization, company size, and asset structure, which are relevant to understanding how agency costs affect the demand for debt. For instance, the current ratio helps assess a company's liquidity, which can impact

the agency costs associated with debt (Myers and Rajan, 1998). Financial performance and asset structure are also analyzed in the context of how they might mitigate or exacerbate agency problems. Market timing theory, on the other hand, posits that managers adjust their capital structure in response to market conditions, such as share price fluctuations. The study incorporates share price performance as a key variable to assess this theory in addition to the company's size. By including these variables, the research can assess whether companies strategically time the issuance of debt and equity to take advantage of market conditions.

While agency theory and market timing theory provide valuable insights into capital structure decisions, both have significant limitations. Agency theory's narrow focus on self-interest and simplistic view of debt overlooks the complexities of modern corporate governance. Market timing theory, on the other hand, overestimates the ability of firms to time the market and fails to address long-term consequences and information asymmetry. As a result, the research involves Total Debt-to-Asset (TDA) as the dependent variable, while it involves six independent variables; Current Ratio (CR), Financial Performance or Profitability (FP), Asset Utilization (AU), Asset Structure or Tangibility (AS), Share Price Performance (SPP), and Size (SR). The variables and the proposed null hypothesis have been summarized in Table 1.

Table 1. The Proposal Null hypothesis in the research

		Agency Theory	Market Timing Theory
1	TDA ~ CR	Negative	
2	TDA ~ FP	Positive	
3	TDA ~ AU	Negative	
4	TDA ~ AS	Positive	
5	TDA ~ SPP		Negative
6	TDA ~ SR	Positive	Negative

Debt Ratio (Debt-to-Assets) [TDA]

The capital structure risk is represented by the debt ratio. Therefore, the greater the debt ratio, the greater the risk is related to debt utilization. As a result, companies may use the debt ratio as an attribute of the financing method either internally or externally. In this research, the equation that was used by Alipour (2015) to calculate the debt ratio will be used in this research,

Debt Ratio = Total Debt / Total Assets

Current Ratio [CR]

The current ratio rates the willingness of a company to cover its current commitments and thus shows adequate financial stability over the short term. Therefore, since the current ratio applies to the current assets and the current liabilities, the current ratio is generally linked to short-term debt. In this

research, the equation that was used by Sheikh and Wang (2011) to calculate the current ratio will be used in this research,

Current ratio (CR) = Current Assets / Current Liabilities

The null hypothesis is,

H01: there is a negative association between the current ratio and the debt ratio.

Financial Performance (Profitability) [FP]

Profitability proves a company's effectiveness in using its overall assets to achieve revenue. According to the agency theory, there is a positive association between profitability and debt because the theory suggests that more debt would motivate a company to spend out the free cash rather than use it in wasteful investments (Bauer, 2004; Acaravci, 2015) and therefore reduce the agency costs (Modugu, 2013). On the other hand, Tong and Green (2004) noted that higher leverage for low-profit companies would raise the risk of bankruptcy and debt expenses and thus reduce the dividend payout. In this research, Earning Before Interest, Tax, Depreciation, and Amortization (EBITDA) will be used. EBITDA is the best variable option to measure profitability, according to (Feidakis and Rovollis, 2007), because it is not influenced by interest, taxation, depreciation, and amortization which may differ between companies. In this research, the equation that was used by Sheikh and Wang (2011) to calculate the financial performance ratio will be used in this research,

Financial Performance (Profitability) (FP) = EBITDA / Total Assets

The null hypothesis is,

H02: There is a positive association between financial performance (profitability) and debt ratio.

Asset Utilization [AU]

The utilization of debt generates an agency cost (Sheikh and Wang, 2011). Therefore, the competitive value of an agency's cost is signified by the utilization of debt and its measured ratio. According to the agency theory, the greater asset utilization, the greater the management efficiency in the adoption and utilization of assets, and thus cost reduction (Jermias, 2008), cash increment, and the need to borrow are reduced (Alipour et al., 2015). Therefore, this ratio is expected to have a negative relationship with the debt

ratio. In this research, the equation that was used by Jermias (2008), and Alipour (2015) to calculate the asset utilization ratio will be used in this research.

Asset Utilization (AU) = Sales / Total Assets

The null hypothesis is,

H03: there is a negative association between asset utilization and debt ratio.

Asset Structure (Tangibility) [AS]

Tangible assets are important because they are collateral that protects a debt (Bhaird and Lucey, 2010) and thus the bankruptcy risk will be reduced (Feidakis and Rovollis, 2007; Cotei and Farhat, 2009; Modugu, 2013; Acaravci, 2015). In the case of bankruptcy, a company with more tangible assets should provide more collateral assets to repay loans and thus would have a better possibility of obtaining more debt (Alipour et al., 2015). The agency theory predicts that the owners in a leveraged business have an opportunity to invest sub-optimally (Titman and Wessels, 1988). In this research, the equation that was used by Sheikh and Wang (2011), and Titman and Wessels (1988) to calculate the asset utilization ratio will be used in this research,

Asset Structure (Tangibility) = Fixed assets / Total Assets

The null hypothesis is,

H04: There is a positive association between asset structure (tangibility) and debt ratio.

Share Price Performance [SPP]

According to the market timing theory, there is a negative relationship between a company's share price and debt (Deesomsak et al., 2004) because when the share price rises, the company issues equity (Antoniou et al., 2008). In this research, ethe quation that was used by Deesomsak et al. (2004), Antoniou et al. (2008), and Alipour (2015) to calculate the share price performance ratio will be used in this research.

Share Price Performance (SPP) = [Share Price (current period) – Share Price (previous period)] / Share Price (previous period)

The null hypothesis is,

H05: There is a negative association between Share Price Performance and debt ratio.

Company's Size [SR]

Unlike trade-off theory, a company's size and debt are negatively related. The presence of this negative relationship may be attributed to the reason that larger companies have the capability to issue new shares rather than issue debt. This means that larger companies utilize less debt in their capital structure (Deloof and Overfelt, 2008). On the other hand, Crutchley and Hansen (1989) proposed five determinants for agency costs: earnings volatility, research and development and advertising expenses, flotation costs, costs due to the diversification of common shares to the management, and size. They found that volatility is significantly negative with leverage, the expense is negative with debt, and positive relationship between size and leverage. Therefore, the research chose the companies' size proxy in order to help distinguish companies' behavior in terms of following either agency theory or market timing theory. In this research, the equation that was used by Sheikh and Wang (2011) to calculate the companies' size will be used in this research,

Size (SR) = ln (Total Assets)

And the null hypothesis is,

H06: There is a negative association between company size and debt ratio.

Methodology

It is important to determine the required statistical analysis in order to determine the sample size and statistical method after completing the research questions and objectives (Golafshani, 2003; Saunders et al., 2012; Collis and Hussey, 2013). Statistical instruments can be utilized to make the statistics significant (Collis and Hussey, 2013). The data that were collected are quantitative in nature and sufficient statistical measures have been implemented to obtain the research goals. The research aims to understand the features and behavior of the companies under observation by consistently observing these companies over a period. Cross-sectional analysis is an

analytical type of approach used to analyze a group of observations at a given point in time. On the other hand, there are some effect detections and measurements that cannot be detected in cross-section or time series statistics. Therefore, to examine the relationship between key financial indicators and a company's debt ratios, the research utilized panel data regression statistics as the primary analytical framework due to its capacity to capture both cross-sectional variations across firms and temporal dynamics within firms, thereby providing more nuanced and reliable estimates than conventional cross-sectional or time-series approaches. According to Saunders et al. (2012), the panel data regression aims to reduce the nested linear overlapping relationships between selected variables, offering better estimates of coefficients.

The advantages of the panel data regression are that, can be used to simulate both collective datasets and individual activities of the community, includes more details, more complexity, and more effectiveness than time series or cross-sectional analysis, and can be used to observe and quantify statistical impacts that are difficult with time series or cross-sectional analysis, can be used to mitigate calculation biases that may result from group aggregation in a single time series. Thus, using the data panel regression has the advantage of discriminating whether individuals are independent of time (Fixed or constant effect across individuals) or not (Random or vary across individuals). Additionally, the methodological approach offers several strengths, including the ability to control unobserved firm-specific factors and temporal trends.

On the other hand, the disadvantage of panel data regression is that it must be modeled accurately by considering the fixed effect versus the random effect. In addition, there is a potential for omitted variable bias, as the model does not account for certain macroeconomic factors or qualitative aspects of corporate governance that may influence capital structure decisions. However, the fixed-effects estimator mitigates some of these concerns by absorbing time-invariant heterogeneity. Since the financial data are subject to reporting conventions and potential inconsistencies inherent in SEC filings, there is a possibility for measurement error. However, the use of standardized reporting formats such as XBRL reduces this risk.

The regression model is formally specified to assess the determinants of corporate leverage, with the total debt ratio (TDA) serving as the dependent variable. Independent variables include the current ratio (CR), financial performance (FP), asset utilization (AU), asset structure (AS), share price performance (SPP), and firm size (SR). The model incorporates fixed effects to account for unobserved heterogeneity across companies and time periods.

Finally, a series of diagnostic tests were conducted to validate the model's assumptions and robustness. In order to detect the outliers in the

datasets, the Mahalanobis Distance has been applied. Then the cumulative distribution Chi-Square has been applied to determine and drop the observations that have a probability of less than or equal to 0.001. In order to detect multicollinearity within dependent variables, Pearson's correlation matrix has been applied. Since the dataset includes observations for companies (individuals) over a quarterly financial period (time), panel data regression was applied. A Lagrange multiplier test has been used in order to determine the appropriate type of panel regression for the collected datasets. Then, the Hausman test was applied in order to determine whether the fixed effect or the random effect is more appropriate. The research used Durbin-Watson statistics to evaluate the first-order serial correlation. In addition, the F-statistics were applied to reflect the validity of the chosen regression.

Data Collection

It is important to determine the required statistical analysis in order to determine the sample size and statistical method after completing the research questions and objectives (Golafshani, 2003; Saunders et al., 2012; Collis and Hussey, 2013). The research aims to understand the features and behavior of the companies under observation by consistently observing these companies over a period. However, there are some effect detections and measurements that cannot be detected in cross-section or time series statistics. Therefore, the research utilized panel data regression statistics. One of the two major categories of data is secondary data, while the other category is primary data. In analysis and statistics, these two types of data are helpful, but for the purpose of this research, the dataset collection has been limited to a secondary dataset because it was downloaded from the website of the United States Security and Exchange Commission (SEC). The datasets that have been downloaded cover the quarterly periods of sixty-four companies between 2012 and 2017 in order to assess and evaluate the selected variables. According to Hox and Boeije (2005), the secondary data must be closely reviewed as to whether they match the relevant research questions. Therefore, an evaluation of the data collection has been conducted in order to obtain answers to the research aims. Since 2009, SEC ordered the registered companies to submit their financial figures using SEC-XBRL model (Hoitash and Hoitash, 2017) as well as sending their financial statements; 10-K and 10-Q in a format that fits the Electronic Data Gathering, Analysis, and Retrieval system (EDGAR) (Dhole et al., 2015) and to be classified in compliance with standardized taxonomies (Dong et al., 2016).

Statistical Model

All proxies that are used in the research have been described, calculated, and derived from the companies' financial statements. The

following regression represents an originally suggested regression that is utilized to study relationships between proposed dependent variables and debt ratio,

$$TDA_{it} = \beta_0 + \beta_1\,CR_{it} + \beta_2\,FP_{it} + \beta_3\,AU_{it} + \beta_4\,AS_{it} + \beta_5\,SPP_{it} + \beta_6\,SR_{it} + \varepsilon_{it}$$

Where:
$\beta_0, \beta_1, \beta_2,\ and\ \beta_3$: are unknown Coefficients.
i: the individual (company)
t: duration (quarterly fiscal period)
ε_{it} : the random error for individual (company) i at duration t

And,

Table 2. Variables

	Initial	Variable	Calculation	Used by
1	TDA	Total Debt Ratio	Total Debt / Total Assets	Alipour (2015)
2	CR	Current Ratio	Current Assets / Current Liabilities	Sheikh and Wang (2011)
3	FP	Financial Performance (Profitability)	EBITDA / Total Assets	Sheikh and Wang (2011)
4	AU	Asset Utilization	Sales / Total Assets	Jermias (2008) and Alipour (2015)
5	AS	Asset Structure (Tangibility)	Fixed Assets / Total Assets	Sheikh and Wang (2011), Titman and Wessels (1988)
6	SPP	Share Price Performance	[Share Price (current period) – Share Price (previous period)] / Share Price (previous period)	Deesomsak et al. (2004), Antoniou et al. (2008), and Alipour (2015)
7	SR	Size Ratio	Ln (Total Assets)	Sheikh and Wang (2011)

Descriptive Statistics

The following table describes the statistical measures of both independent and dependent variables. The table shows that companies, on average, rely less on debt but more on their assets in financing their operations. On the other hand, since the median is less than the mean, companies tend to reduce their debt-to-asset ratio. The negative mean sign and the positive median sign of the share price performance show that most companies issue new shares, while there are a few big companies that repurchase a high amount of their shares and this behavior is in line with the mean and median of

companies' size. The high mean value of the current ratio shows that companies have either high credit sales, high inventory levels or high cash and cash equivalent amounts. The mean value of financial performance is negative, while median is positive. This means that companies experience a loss with constant pursuit of profit.

Table 3. Descriptive Statistics

		CR	FP	AU	AS	SPP	SR	TDA
1	Min.	0.05519	-6.727287	0.01406	0.004746	-5.995114	10.53	0
2	1st Qu.	1.53315	0.009406	0.34505	0.124857	0	19.49	0.4786
3	Median	2.06854	0.033559	0.62706	0.299155	0.000366	20.54	0.561
4	Mean	4.00006	-0.046786	0.82148	0.313243	-0.005022	20.16	0.718
5	3rd Qu.	6.22737	0.069419	1.0617	0.48201	0.002977	21.7	0.6843
6	Max.	20.87213	0.561899	5.27249	0.957999	0.999992	23.54	11.7417

Outliers and Multicollinearity

In order to detect the outliers in the datasets, the Mahalanobis Distance has been applied. Then the cumulative distribution Chi-Square has been applied to find and drop the observations that have a probability less than or equal to 0.001. In order to detect multicollinearity within dependent variables, Pearson's correlation matrix has been applied as shown in Table 4. The inter-correlation is less than 0.7 for all variables, which keeps the proposal regression to estimate TDA valid, and the robustness test will not be needed.

Table 4. Pearson Correlation Matrix

		CR	FP	AU	AS	SPP	SR
1	CR	1	0.136833	-0.3793	-0.60128	-0.02322	0.299217
2	FP	0.136833	1	-0.34973	0.094442	-0.01871	0.519895
3	AU	-0.3793	-0.34973	1	0.138172	0.055363	-0.40161
4	AS	-0.60128	0.094442	0.138172	1	0.027717	0.052418
5	SPP	-0.02322	-0.01871	0.055363	0.027717	1	-0.03377
6	SR	0.299217	0.519895	-0.40161	0.052418	-0.03377	1

Regression Model

Table 05 shows that the Lagrange multiplier test was statistically significant (p-value < 0.001) and thus the panel data model (fixed or random) is preferred over the pooled model. The Hausman test showed that the p-value is less than 0.001, which shows that the null hypothesis is rejected, and the fixed effect is proper. On the other hand, the Durbin-Watson statistics showed that errors are not correlated, and the F-statistics showed statistically significan resultst, reflecting the validity of the chosen regression.

Table 5. Regression model results

Variables	TDA
CR	-0.077***
	(-6.624)
FP	-0.132***
	(-3.601)
AU	0.366***
	(9.888)
AS	0.153
	(0.810)
SPP	0.009
	(0.237)
SR	-0.367***
	(-7.955)
Fixed time effects	Yes
Fixed cross-section effects	Yes
No. of Observations	1114
R-Squared	0.22561
Adjusted-R^2	0.15251
F-statistics	49.3819***
Durbin-Watson	2.3187
Lagrange Multiplier	20.753***
Hausman test	< 0.001

Notes: The dependent variable includes *Debt-to-Assets (TDA)* equals the Total Debt of companies divided by the Total Assets at the end of the fiscal quarter.

The independent variables, including *Current Ratio (CR),* are equal to Current Assets divided by Current Liabilities at the end of the fiscal quarter. *Financial Performance or Profitability (FP)* is equal to EDITDA divided by Total Assets at the end of the fiscal quarter. *Assets Utilization (AU)* equals Net Sales divided by Total Assets at the end of the fiscal quarter. *Asset Structure or Tangibility (AS)* equals Fixed Assets divided by Total Assets at the end of the fiscal quarter. *Share Price Performance (SPP)* equals [(Share Price (current fiscal quarter) – Share Price (previous fiscal quarter)] / Share Price (Previous fiscal quarter). *Size (SR)* equals ln (Total Assets) at the end of the fiscal quarter.

T-statistics are in parentheses beneath coefficient estimates.

*** Significant at 0.01

** Significant at 0.05

* Significant at 0.1

From table-5, the results confirm a statistically significant negative relationship between the current ratio (CR) and debt ratio and thus the null hypothesis H01 cannot be rejected at significance level 0.001. This suggests that companies with higher liquidity prefer lower debt levels, possibly to avoid financial distress or to maintain flexibility. A higher current ratio indicates stronger short-term solvency, reducing the need for external borrowing. This aligns with the pecking order theory, where companies prioritize internal financing over debt. On the other hand, from an agency theory perspective,

managers of companies with higher liquidity may avoid debt to minimize monitoring from creditors, which supports the negative relationship.

Contrary to expectations, financial performance (FP) exhibits a significant negative relationship with debt ratio and thus H02 is rejected. This contradicts the trade-off theory, which posits that profitable companies use more debt to benefit from tax shields. Instead, the findings align with the pecking order theory, where companies with higher profitability rely on retained earnings rather than external debt. Agency theory further explains that managers may avoid debt to reduce bankruptcy risk and maintain discretionary control over free cash flows rather than committing to fixed repayments.

The regression reveals a significant positive relationship between asset utilization (AU) and debt ratio and thus the null hypothesis H03 is rejected. This implies that companies with higher asset efficiency tend to carry more debt, possibly because lenders view efficient asset use as a sign of lower risk and higher collateral value, which increases debt capacity. Alternatively, companies with high asset utilization may take on more debt to finance growth. This finding does not directly align with agency theory, which predicts that high-efficiency companies might avoid debt to prevent creditor interference. However, it could fit the market timing theory if companies capitalize on favorable borrowing conditions when asset performance is strong.

The asset structure (AS), or tangibility, shows a positive but statistically insignificant relationship with debt ratio. The positive relationship is as proposed in the null hypothesis but not significant with debt ratio and thus the null hypothesis H04 is rejected. While trade-off theory suggests that tangible assets facilitate debt financing by providing collateral, the lack of significance implies that other factors (e.g., growth opportunities, industry risks) dominate. In other words, while tangibility is often expected to increase debt capacity due to collateral value, the lack of significance suggests that other factors, such as industry-specific characteristics or macroeconomic conditions, may play a more dominant role. For example, companies with high intangible assets (e.g., tech companies) may rely more on equity financing despite lower tangibility, diluting the expected positive relationship. On the other hand, Agency theory predicts that companies with higher tangible assets have a higher debt ratio due to lower asset substitution risks, but the weak relationship suggests that creditors may not rely solely on collateral. The positive relationship does not strongly align with market timing theory, as tangibility is a structural factor rather than a market-driven one.

The results show no significant relationship between share price performance (SPP) and debt ratio, and thus the null hypothesis H05 is rejected, which contradicts market timing theory. In addition, the lack of significance implies that companies do not adjust leverage based on short-term stock

performance, possibly because capital structure decisions are driven by long-term financial strategies rather than market fluctuations or possibly because managers prioritize fundamental financial metrics over short-term stock movements when determining leverage.

The results support H06, showing a significant negative association between company size (SR) and the debt ratio and thus the null hypothesis H06 cannot be rejected. Larger companies, often with diversified revenue streams and lower bankruptcy risk, may rely more on retained earnings or equity financing. Conversely, smaller companies might use higher debt to overcome size disadvantages. Though the negative relationship here suggests larger companies exploit non-debt advantages, such as better access to equity markets. Agency theory suggests that large companies face lower asymmetric information costs, which allows easier equity issuance, while market timing theory could explain this if larger companies time equity issuances during favorable market conditions, which reduces reliance on debt.

Conclusion

The datasets were downloaded from the United States Security and Exchange Commission (SEC) and comprised sixty-four companies between 2012 and 2017. Due to the dataset nature which contains individual effects that vary over time, a panel data regression was used. The research aims to define the potential determinants in terms of their compatibility with the agency theory and market timing theory. Therefore, the research analyzed many determinants in order to investigate their impacts on the debt ratio and to assess the consistency of these determinants with the agency theory and market timing theory. The research explores numerous credential literature to articulate the critical issues in capital structure from the perspective of these two theories. Moreover, the research explores the capital choice decision process of a company. Therefore, the companies' performance was investigated as a reflection of total agency costs through investigating the relationship between the performance and debt ratio. Furthermore, this research has been designed to provide an extensive explanation of the agency and market timing theories.

The findings showed that the companies in the datasets prefer debt to equity issuance. The negative relationship between liquidity, current ratio (CR), and debt ratio is consistent with attempts by the companies to explain the agency costs as a result of a possible dispute between creditors and owners, and between companies' management and owners (Modugu, 2013). According to Acaravci (2015), debts lower the tax liability of the companies and raise the post-tax cash flow to dividends. The negative relationship between companies' size and debt ratio may indicate that larger companies tend to have more investments that produce more profits, which enable them

to sustain a possible low level of debt. The statistically significant negative relationship between the current ratio (CR) and debt (TDA) is consistent with the principle of agency theory. The negative association suggests that debts do not need to be used by companies with enough liquidity and thus have a lower debt ratio. Moreover, according to the agency theory, the negative association can be interpreted as justifying the increasing agency costs due to the possible dispute between lenders and the owners and between the management and the owners (Modugu, 2013). Myers and Rajan (1998) argued that the reason for this negative relationship is that as the liquidity of an agency's costs are raised, the outside lenders restrict and reduce the amount of debt accessible to the company. In addition, the results are consistent with Eriotis et al. (2007), and Sheikh and Wang (2011).

The negative relationship between financial performance, profitability (FP) and debt (TDA) is not consistent with the agency theory. This indicates that while agency theory explains some aspects of capital structure decisions, market timing theory and the pecking order theory offer additional insights. This result has also been confirmed by the negative relationship between companies' size (SR) and debt (TDA) and by the positive relationship between asset utilization (AU) and debt (TDA). On the other hand, the results are consistent with the pecking order theory (Bauer, 2004; Sheikh and Wang, 2011; Mateev et al., 2013; Modugu, 2013; and Acaravci, 2015). Furthermore, Bauer (2004) reported a positive relationship between profitability and short-term debts, while long-term debt profitability has a negative relationship. This means that companies depend more on long-term debt than short-term debt.

The asset structure (tangibility) (AS) shows an insignificant statistically positive relationship with debt (TDA). The positive relationship is consistent with the agency theory and with the results of Titman and Wessels (1988). According to the trade-off theory, there is a positive relationship between debt and tangibility because the more tangibility, or fixed assets, the more ability to have more debt, because the more fixed assets shift the bankruptcy point upward. Tangible assets may have a negative relationship with debt through growing risk by increased operational leverage (Hutchinson and Hunter, 1995). On the other hand, according to the pecking order theory, companies with high tangible assets have a minor issue in terms of asymmetry information, while companies with low tangible ratios would prefer to issue new equity.

The positive relationship between asset utilization (AU) and debt (TDA) can be interpreted as the ownership continues to have a significant part in the decision-making on the capital structure of the companies (Alipour et al., 2015). The insignificant statistically positive relationship of share price performance (SPP) with debt (TDA) indicates that companies tend to prefer debt to equity regardless of the market situation. The significant statistical

negative relationship between a company's size (SR) and debt (TDA) indicates that larger companies appear to have a reduced debt level due to their willingness to issue new equity (Sheikh and Wang, 2011; and Degryse et al., 2012) than debt. Eriotis et al. (2007) concluded that larger companies had more varied investments and thus less chance of bankruptcy. Thus, their size helps them to sustain a relatively high debt level (Daskalakis and Paillaki, 2008; Bhaird and Lucey, 2010). The presence of the negative relationship may be attributed to the reason that larger companies have the capability to issue new shares rather than issue debt. On the other hand, the positive relationship is contrary to Crutchley and Hansen's (1989) results, which indicated that companies' behavior was not consistent with the agency theory.

The findings of this research contribute to the ongoing discourse in corporate finance by providing empirical evidence that supports and challenges agency theory and market timing theories. Specifically, the study reinforces the relevance of agency theory in explaining the relationship between liquidity and debt levels. A critical examination of the theoretical assumptions against empirical results reveals some limitations in both theories. Agency theory assumes that managers always act in their self-interest, but the findings suggest that other factors, such as market conditions, also play a significant role in capital structure decisions. While agency theory predicts that higher profitability should lead to more debt, the results indicate the opposite, aligning with the pecking order theory. This suggests that the assumption that management always prioritizes their interests might be too simplistic. However, it also highlights the limitations of agency theory in fully explaining the complex interplay between profitability, company size, asset utilization, and capital structure. The results suggest that the pecking order theory may offer a more comprehensive framework for understanding these relationships in the context of the companies studied. Additionally, while market timing theory is useful in explaining short-term capital structure adjustments, the research does not lend dedicated support to market timing theory, as share price performance did not exhibit a significant relationship with debt ratios. This suggests that, for the companies in this sample, market conditions may not be a primary driver of capital structure decisions, which suggests that behavioral and institutional factors also play a crucial role in shaping financing decisions.

Since the goal of the stockholders is to maximize their wealth and benefits that may result from stock price increments, the alignment between the interests of ownership and management is related to financial preferences and action alignments (Nyberg et al., 2010). Therefore, the management compensation should be well planned in order to motivate the management to safeguard the interests of the owners. (Kim and Gu, 2005). One of the agency's costs is the extra costs of debt that is needed to confine management behavior.

According to the agency theory, managements tend to reduce these costs by announcing them in the financial statement (Abdullah and Ismail, 2008). Management is better rewarded based on certain performance indices such as profitability and increase in stock prices. (Kim and Gu, 2005). The findings suggest that financing decisions are influenced by a combination of internal factors (such as liquidity and profitability) and external constraints (such as debt accessibility), rather than purely theoretical predictions. For financing practices, the findings highlight the importance of context-specific capital structure strategies. Decision makers and financial managers should consider company-specific determinants, such as liquidity and asset utilization, when designing financing policies, rather than relying solely on theoretical frameworks. In terms of policy, the findings suggest that regulators should continue to promote transparency and accountability in corporate financial reporting to minimize information asymmetrical and agency problems.

Since the research introduced an empirical study on selected companies listed in the U.S. Exchange, it may limit the generalizability of the findings to private companies or companies operating in other markets, particularly those with different regulatory environments and financial structures. Therefore, more empirical research may extend the findings by analyzing them across developed markets as well as various stock markets. Further research could also explore the role of other potential determinants of capital structure, such as corporate governance mechanisms, institutional ownership, and the quality of financial reporting.

Finally, both agency theory and market timing theory provide valuable frameworks for understanding capital structure decisions, but neither theory alone can fully explain the complexities observed in real-world corporate financing behavior. Finally, this study advances the understanding of capital structure determinants while challenging the rigid application of agency and market timing theories. By integrating empirical findings with theoretical frameworks, it paves the way for more nuanced and context-aware financial decision-making. Future research should build on these insights to develop holistic models that account for the complexities of modern corporate finance.

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Analysis of the determinants influencing the choice of local market garden crops: tomato, chili, onion, krinkrin, and okra in Southern Benin

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Abstract

For over two decades, Benin has experienced a steady rise in market gardening production. However, this growth has not translated into self-sufficiency, as the country continues to rely on imports from neighboring nations during lean seasons. Analyzing the factors influencing the choice of local market garden crops could provide valuable insights for addressing this issue. This study employed a multivariate probit model to identify the determinants influencing the adoption of specific market garden crops, namely tomato, pepper, onion, krinkrin, and okra, on farms in southern Benin. The research was conducted using a randomly selected sample of 474 market gardeners. Findings revealed interdependence and complementarity in the adoption of the various crops studied. Notably, most surveyed producers preferred adopting combinations of either two (27.43%) or four (25.74%) crops at a time. Moreover, key factors influencing crop adoption included the presence of a local market, the farmers' level of education, access to a telephone network, the nature of the area, particularly its proximity to the water table, and the security of farming sites.

Keywords: Determinants, Southern Benin, Market Gardening, Multivariate Probit

Introduction

Market gardening is practiced in all regions of Benin. It represents a varied food source that supplements the population's basic food needs (Adjatini et al., 2019; Bognini, 2011). They contribute significantly to food security, job creation and income for many producers in peri-urban and rural areas of Benin (Sikirou *et al.*, 2001), hence their importance in reducing household poverty (Babah-Daouda and Yabi, 2021). These crops are also essential to human health due to their contribution of trace elements, particularly vitamins and mineral salts (Shiundu, 2002; Stevels, 1990).

In Benin, market garden production experienced a real boom between 2003 and 2013, rising from 241,399 tons to 549,310 tons of market garden produce per year (Babah-Daouda and Yabi, 2021). According to DSA/MAEP (2024), the total market garden production during the 2023-2024 season is estimated at 717,365 tons compared to 675,188 tons in the 2022-2023 season. Despite the upward trend, the distribution of market garden products remains poorly regulated across markets. This very often leads to periods of overabundance, causing price drops in certain markets and numerous post-harvest losses, especially in a context where processing remains rudimentary and underdeveloped. Moreover, during periods of shortage, we generally observe imports from neighboring countries such as Niger, Burkina Faso and Nigeria (Allogni *et al*., 2015).

This is why this study focuses on analyzing the determinants influencing the choice of local market garden crops, including tomato, pepper, onions, krinkrin and okra in southern Benin, in order to identify appropriate solutions to improve local crop adoption. By exploring the interactions between the socio-economic characteristics of farmers, the specificities of the study region and market dynamics, this analysis will be able to provide crucial information to support the development of more efficient and sustainable agricultural strategies.

Methodology

Rogers' theory of adoption of agricultural practices or innovations states that adoption remains an individual decision (Rogers, 2003). According to Varian (2008), the adoption decision is generally based on the principle of rationality as defined by neoclassical economic theory. Thus, the producer adopts a new technology or makes a choice if and only if it allows him to maximize his utility. In the same vein, a producer will adopt a vegetable crop if the expected utility, represented by $U1\ (\pi)$, is higher than that which he would obtain if he had not adopted it, represented by $U0\ (\pi)$, i.e., $U1\ (\pi) > U0\ (\pi)$. However, the utility that the producer obtains from the adoption of one or the other of the vegetable crops is not observable. It nevertheless depends on the socioeconomic, demographic, institutional and environmental

characteristics of the said producer noted (Xi) and can be represented by the following latent variable: $Ui = Xi\beta + \varepsilon i$, $i = 1,2, \ldots, N$ (1); where β is the vector of coefficients and εi is the random disturbance term.

In this case, the analytical approaches most often used in decision studies on the choice of a crop to estimate equation 1 are maximum likelihood estimation. When the decision involves a single crop, making the dependent variable dichotomous a univariate Logit or Probit model is generally applied (Lansink *et al.*, 2003). On the other hand, when the choice must be made between several possible alternative market garden crops, the literature recommends using either multinomial or multivariate Logit or Probit models.

Multinomial models are based on the independence of irrelevant alternatives, i.e., the error terms of the choice equations of the alternatives are mutually exclusive (Greene and Hensher, 2003). However, choices among market garden crops in southern Benin are not mutually exclusive; the producer could adopt a given market garden crop and consider adopting another. Therefore, the random error terms of the different market garden crop adoption equations may be correlated. In such circumstances, the estimation of multinomial Logit or Probit models would lead to biased estimators (Greene, 2008).

Vegetable crops are classified into local or traditional crops and exotic crops through literature (Simeni et al., 2009; Traoré, 2022). Moreover, leafy vegetables also stand out due to their usefulness (Shiundu, 2002; Stevels, 1990). For this reason, this study will focus on the choice of market garden crops by homogeneous groups for greater consistency and tangible results. Therefore, this first phase of our work focuses on tomato, pepper, onions, krinkrin and okra.

As mentioned earlier, producers tend to adopt several vegetable crops at once in order to maximize their profits. Therefore, and based on the empirical literature on adoption (Kassie *et al.*, 2015), all complementary innovations in terms of utilities that they allow the producer to gain and maximize will be adopted by the latter. This stipulates an interdependence of the producer's decisions to adopt each of these vegetable crops. In other words, the decision to adopt vegetable crop j by producer I would depend on the decision to adopt vegetable crop k, and so on. When interdependence in agricultural technology adoption decisions is suspected, the literature advises the use of a multivariate probit regression model for unbiased estimation of the estimators (Timu et al., 2014; Wu and Babcock, 1998). Multivariate probit is an extension of the bivariate probit model that uses Monte Carlo simulation techniques to simultaneously estimate the system of multivariate probit regression equations (Greene, 2008). To achieve this, the simultaneous

adoption of tomato[1], pepper[2], onion[3], krinkrin[4,] and okra[5] can be modeled by a system of dichotomous adoption equations (2) as follows: $\{Y_1 = 1\ si\ U_{1*}^* > U_{0*}^*\ Y_1 = 0\ if\ not\ Y_2 = 1\ si\ U_{2*}^* > U_{0*}^*\ Y_2 = 0\ if\ not\ Y_3 = 1\ si\ U_{3*}^* > U_{0*}^*\ Y_3 = 0\ if\ not\ Y_4 = 1\ si\ U_{4*}^* > U_{0*}^*\ Y_4 = 0\ if\ not\ Y_5 = 1\ si\ U_{5*}^* > U_{0*}^*\ Y_5 = 0\ if\ not$

(2)

The multivariate probit regression model was adopted to estimate the probability of adoption of market garden crops (equation 2) in order to take into account possible correlation between the error terms of the different binary adoption equations (Greene, 2008). The multivariate probit model has already been used in a number of empirical studies assessing the factors influencing the simultaneous adoption of several agricultural technologies (Adekambi et al., 2021; Dassoundo-Assogba et al., 2019). The empirical model estimated with the variables included in the estimations is presented as follows:

$$CULTj = \alpha 1\beta i + \alpha 2\beta i + \alpha 3\beta i + \ldots + \alpha n\beta i + \varepsilon i \ (3)$$

With CULTj the set of dependent variables includes tomato, chili, onion, krinkrin, and okra. Each dependent variable in equation (3) is a binary variable that takes the value 1 if producer i adopts vegetable crop j (with j = tomato, chili, onion, krinkrin and okra) and 0 if not. The different independent variables used in the estimation of the multivariate probit model are described in Table 1.

Table 1: Description of independent variables included in the estimated models

Variables	Description	Terms and conditions
Gender	Gender	Binary variable (0=Female, 1=Male)
Age range	Age group	Binary variable (0=Young, 1=Adult)
Mb_coop	Cooperative member	Binary variable (0=no, 1=yes)
Nv_instruction	Educational level	Categorical variable (0=None, 1=Primary, 2=Secondary 1, 3=Secondary 2, 4=Higher)
Market gardening experience	Experience in market gardening	Categorical variable (0=Beginner, 1=Junior, 2=Confirmed, 4=Senior)
Form_prof	Vocational training	Binary variable (0=no, 1=yes)
Exist_struct	Existence of a market gardening promotion structure	Binary variable (0=no, 1=yes)

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[1] Solanum lycopersicum
[2] Capsicum annuum
[3] Allium cepa
[4] Corchorus olitorius
[5] Abelmoschus esculentus

Variables	Description	Terms and conditions
Exist_support	Existence of market gardening support advice	Binary variable (0=no, 1=yes)
Exist_electri	Existence of electricity	Binary variable (0=no, 1=yes)
Exist_teleph	Existence of the telephone	Binary variable (0=no, 1=yes)
Access_site	Site accessibility	Categorical variable (0=Road in poor condition and not accessible, 1=Road in poor condition and accessible, 2=Road in good condition but not accessible, 3=Road in good condition and accessible)
Exist_march	Existence of a nearby market	Binary variable (0=no, 1=yes)
Exist_secure	Existence of a secure site	Binary variable (0=no, 1=yes)
Type_tablecloth	Type of water table	Categorical variable (0=Lowland zone, 1=Coastal barrier zone, 2=Intermediate water table zone, 3=Deep water table zone)

This study was carried out in the southern part of Benin, between 6°10 and 6°45 North latitude, and 1°34 and 2°48 East longitude. This region covers the departments of Atlantique, Littoral, Mono, Couffo, Oueme, Plateau and Zou. It is characterized by an equatorial climate with high humidity and a seasonal cycle marked by alternating dry and rainy periods. In this region, market gardening is practiced both in the rainy season and during the dry season, with cultivation techniques adapted to each climatic condition.

In this study, the basic unit of analysis is the market gardeners. For the survey, they were targeted at sites in southern Benin from the coast to Djidja, approximately 150 kilometers from Cotonou. The choice of these sites in Benin is explained by their importance in market gardening production and the diversity of market garden crops. The market gardeners surveyed were randomly selected to obtain a representative sample of the study population and to ensure the reliability of the results. A total of 474 market gardeners were surveyed.

Table 2: Sample size

PDA	Investigated	Percentage (%)	Cumulative (%)
4	17	3.59	3.59
5	125	26.37	29.96
6	47	9.92	39.87
7	285	60.13	100.00
Total	**474**	**100.00**	

As part of this study, the primary, quantitative and qualitative data deemed necessary were collected from November to December 2024. Initially,

an exploratory phase allowed contact with the resource persons in the study area in order to better plan the survey. It also allowed us to become familiar with local realities and to readjust certain details of the questionnaire. In a second phase, the actual data collection was carried out through direct interviews using a structured questionnaire, administered individually to market gardeners using the KoboCollect tool. Unstructured interviews were also conducted in order to obtain as much information as possible. The data collected relates to the socioeconomic and demographic traits of market gardeners, the adoption of market gardening crops, experience, the working environment of market gardeners, the management tools used, and quantitative data (area available and used, etc.).

Stata 14.0 software was used to analyze the data through the multivariate probit regression model (Greene, 2008) applied to market garden crops including tomato, pepper, onion, horseradish and okra. The multivariate probit model has already been used in a number of empirical studies evaluating the factors that influence the simultaneous adoption of several agricultural technologies (Adekambi et al., 2021; Dassoundo-Assogba et al., 2019).

Results

Table 3 analyzes the sociodemographic and economic characteristics of the surveyed market gardeners based on their membership in agricultural development clusters. The analysis considered factors such as gender, age group, cooperative involvement, education level, experience, and security of production sites.

Table 3: Descriptive statistics of variables according to the agricultural development pole

Variables	Terms and conditions	Agricultural Development Poles (PDA)				Total	Comparison test
		PDA 4	PDA 5	PDA 6	PDA 7		
Gender	Women	7.1%	30.7%	10.2%	52.0%	100.0%	Pearson chi2(3) = 9.1016 Pr = 0.028
	Man	2.3%	24.8%	9.8%	63.1%	100.0%	
Age group	Young	1.1%	25.4%	11.8%	61.8%	100.0%	Pearson chi2(3) = 13.7063 Pr = 0.003
	Adult	6.9%	27.7%	7.4%	57.9%	100.0%	
Cooperative member	No	4.4%	46.7%	28.9%	20.0%	100.0%	Pearson chi2(3) = 39.2336 Pr = 0.000
	Yes	3.5%	24.2%	7.9%	64.3%	100.0%	
Educational level	None	11.7%	45.0%	0.0%	43.3%	100.0%	Pearson chi2(12) = 46.2159 Pr = 0.000
	Primary	5.8%	34.6%	7.7%	51.9%	100.0%	
	Secondary 1	2.8%	28.4%	9.2%	59.6%	100.0%	
	Secondary 2	2.5%	21.5%	15.7%	60.3%	100.0%	
	Superior	0.8%	17.4%	10.6%	71.2%	100.0%	
Experience in market gardening	Beginner	0.0%	50.0%	0.0%	50.0%	100.0%	Pearson chi2(9) = 20.1447 Pr = 0.017
	Junior	1.8%	36.4%	8.2%	53.6%	100.0%	
	Confirmed	3.9%	26.0%	14.9%	55.2%	100.0%	
	Senior	4.4%	20.4%	6.1%	69.1%	100.0%	
Vocational training	No	4.1%	27.2%	8.9%	59.8%	100.0%	

Variables	Terms and conditions	Agricultural Development Poles (PDA)				Total	Comparison test
		PDA 4	PDA 5	PDA 6	PDA 7		
	Yes	2.2%	24.3%	12.5%	61.0%	100.0%	Pearson chi2(3) = 2.6451 Pr = 0.450
Existence of a market gardening promotion structure	No	7.7%	37.0%	6.1%	49.2%	100.0%	Pearson chi2(3) = 36.8274 Pr = 0.000
	Yes	1.0%	19.8%	12.3%	66.9%	100.0%	
Existence of market gardening support advice	No	0.0%	51.4%	16.2%	32.4%	100.0%	Pearson chi2(3) = 17.6616 Pr = 0.001
	Yes	3.9%	24.3%	9.4%	62.5%	100.0%	
Existence of electricity	No	4.7%	28.4%	12.8%	54.0%	100.0%	Pearson chi2(3) = 7.5583 Pr = 0.056
	Yes	2.7%	24.7%	7.6%	65.0%	100.0%	
Existence of the telephone	No	0.0%	36.7%	15.2%	48.1%	100.0%	Pearson chi2(3) = 12.1812 Pr = 0.007
	Yes	4.3%	24.3%	8.9%	62.5%	100.0%	
Site accessibility	Road in poor condition and not accessible	5.9%	5.9%	0.0%	88.2%	100.0%	Pearson chi2(9) = 108.5081 Pr = 0.000
	Road in poor condition and accessible	10.7%	27.3%	16.5%	45.5%	100.0%	
	Road in good condition but not accessible	0.0%	6.5%	5.7%	87.8%	100.0%	
	Road in good condition and accessible	1.0%	41.8%	10.2%	46.9%	100.0%	
Existence of a nearby market	No	5.1%	34.8%	12.9%	47.3%	100.0%	Pearson chi2(3) = 38.6070 Pr = 0.000
	Yes	1.8%	16.5%	6.4%	75.2%	100.0%	
Existence of a secure site	No	0.9%	21.5%	14.0%	63.6%	100.0%	Pearson chi2(3) = 6.5717 Pr = 0.087
	Yes	4.4%	27.8%	8.7%	59.1%	100.0%	
Type of water table	Lowland area	0.0%	19.8%	4.1%	76.2%	100.0%	Pearson chi2(9) = 116.8136 Pr = 0.000
	Coastal barrier area	0.0%	9.8%	2.4%	87.8%	100.0%	
	Intermediate water table zone	3.0%	45.0%	18.0%	34.0%	100.0%	
	Deep water table zone	11.7%	31.7%	16.7%	40.0%	100.0%	

Variables such as vocational technical training, the availability of electricity and the availability of a secure site do not vary significantly depending on the PDA.

On the other hand, gender, age group, membership of a cooperative, level of education, experience in market gardening, existence of market gardening promotion structure, existence of market gardening advisory support, existence of a telephone network, accessibility of the site, existence

of a market close to the site, type of water table very significantly from one PDA to another.

Table 4 presents the adoption rates of local market garden crops among producers. Pepper shows the highest adoption rate (78.48%), followed by tomato (49.58%), okra (39.87%), krinkrin (31.43%) and onion (17.93%). The analysis of the combined adoption of different market garden crops reveals that the majority of producers opt for two crops at a time, i.e., 27.43% of the producers interviewed. Also, 25.74% of the producers surveyed practiced four crops at a time compared to 18.99% for the three crops, 10.13% for one crop and 3.80% for none of these five crops studied.

Table 4: Adoption rate of market gardening crops

	Adopters	Percentage (%)
Agricultural crop adoption rate		
Capsicum annuum (Pepper)	372	78.48
Solanum lycopersicum (Tomato)	235	49.58
Okra (Abelmoschus esculentus)	189	39.87
Krinkrin (Corchorus olitorius)	149	31.43
Onion (Allium cepa)	149	17.93
Number of crops adopted at a time		
No crop	48	3.80
One crop	130	10.13
Two crops	90	27.43
Three crops	122	18.99
Four crops	66	25.74
Five crops	18	13.92

The analysis of the determinants of the choice of market garden crops was approached by assuming the different possible market gardening systems. To this end, it is noted through the literature that Traoré (2022) proposes a categorization of market garden crops, namely local or traditional species such as okra, tomato, leafy vegetables, etc., then exotic species such as lettuce, cabbage, carrot, etc. Going practically in the same direction, Simeni et al. (2009). He mentioned the existence of three main market gardening systems, namely the traditional crop system, the exotic crop system and the mixed crop system.

Drawing from Yao et al. (2015) study on leafy vegetables in local or traditional agriculture, we propose further subdivisions to better understand market garden crop choice. Given the literature's emphasis on leafy vegetables as key sources of medicinal compounds and micronutrients (Shiundu, 2002; Stevels, 1990), we single them out for analysis. This leads to our first multivariate probit model, focusing on tomato, pepper, onions, krinkrin, and okra.

Table 5 presents the estimation results of the first multivariate probit model, which analyzes the adoption of local crops: tomato, chili, onion, krinkrin, and okra.

Table 5: Estimation of the multivariate probit model

	Tomato Coef (Z Test)	Pepper Coef (Z Test)	Onion Coef (Z Test)	Krinkrin Coef (Z Test)	Okra Coef (Z Test)
Location of the agricultural development center	0.132 (1.68*)	0.184 (2.05**)	0.255 (2.70***)	-0.0009 (-0.01)	-0.078 (-1.07)
Membership in a cooperative	-0.599 (-2.27**)	-0.536 (-1.88*)	0.157 (0.47)	-0.275 (-1.08)	0.242 (0.95)
Gender	0.0402 (0.25)	0.408 (2.46**)	-0.034 (-0.18)	-0.428 (-2.80***)	-0.121 (-0.81)
Educational level	0.249 (4.24***)	0.052 (0.90)	0.144 (2.12**)	0.151 (2.59***)	0.112 (2.09**)
Accessibility of the village	0.026 (0.38)	-0.369 (-4.48***)	0.174 (2.24**)	-0.114 (-1.69*)	-0.071 (-1.11)
Existence of electrical energy	-0.333 (-2.31**)	0.217 (1.41)	0.215 (1.32)	0.180 (1.28)	-0.041 (-0.32)
Existence of telephone network	0.90 (54.68***)	-0.024 (-0.12)	0.765 (3.07***)	0.592 (3.02***)	0.537 (3.06***)
Existence of a market in the village	-0.640 (-4.40***)	-0.519 (-3.22***)	-0.499 (-3.05***)	-0.480 (-3.40***)	-0.423 (-3.14***)
Existence of a market gardening promotion structure	0.006 (0.05)	0.019 (0.12)	0.466 (2.65***)	0.185 (1.28)	0.049 (0.36)
Use of farm management tools	-0.581 (-3.06***)	-0.261 (-1.25)	0.023 (0.11)	-0.665 (-3.59***)	-0.048 (-0.27)
Site security	0.280 (1.59)	1.10 (6.08***)	0.445 (2.29**)	0.391 (2.19**)	0.398 (2.32**)
Type of area related to the proximity or not of the water table	0.420 (7.27***)	-0.041 (-0.67)	0.150 (2.14**)	-0.027 (-0.50)	0.138 (2.59**)
Age group	0.161 (1.06)	0.109 (0.66)	0.239 (1.41)	0.095 (0.64)	0.077 (0.54)
Level of professional experience in market gardening	-0.033 (-0.35)	-0.070 (-0.68)	0.352 (3.08***)	-0.297 (-3.24***)	-0.084 (-0.95)
Number of observations = 474 Wald chi2(70) = 316.66 Prob > chi2 = 0.0000 Log likelihood = -1139.5858					
	Coefficient (z test)			Coefficient (z test)	
rho21	0.541 (7.92***)		**rho42**	0.3745418 (4.61***)	
rho31	0.465 (5.87***)		**rho52**	0.2266077 (2.93***)	
rho41	0.269 (3.68***)		**rho43**	-0.0231471 (-0.26)	
rho51	0.235 (3.26***)		**rho53**	0.0908882 (1.08)	
rho32	0.197211 (2.08**)		**rho54**	0.358327 (5.20***)	
Log likelihood: rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho > 54 = 0: chi2(10) = 127.548 Prob > chi2 = 0.0000					

The likelihood ratio test for the overall correlation of error terms in the different models (chi2 (10) = 127.548; p < 0.001) is significantly different from zero at the 1% level and therefore allows us to reject the hypothesis of the independence of the choices of the different crops analyzed. The decision

to adopt a market garden crop between tomato, chili, onion, krinkrin and okra is therefore determined by that of another and vice versa.

On the other hand, the correlation between the decision to adopt krinkrin and onion is negative and not significant at the 1% level (rho = -0.023; p > 0.01). This is also the case with the correlation between the decision to adopt okra and onion, which was found to be positive and not significant at the 1% level (rho = 0.908; p > 0.01).

The correlations between the decisions to adopt pepper and tomato, onion and tomato, krinkrin and tomato, okra and tomato, onion and pepper, krinkrin and pepper, okra and pepper, okra and krinkrin are all positive and significant at the 1% level (rho_{21}=0.541; rho_{31}=0.465; rho_{41}=0.2692; rho_{51}=0.235; rho_{32}=0.197 rho_{42}=0.3745; rho_{52}=0.226 and rho_{54}=0.358; p < 0.001).

From this same table, it appears that the variables that significantly influence the adoption of at least one of the five market gardening crops are: the level of education (positively), the existence of a telephone network (positively), the existence of a market in the village (negatively), the use of farm management tools (negatively), the type of area in relation to the proximity or not of the water table (positively), the accessibility of the village, the security of the site (positively), the location of the agricultural development center, the existence of a market gardening promotion structure (positively), the level of professional experience in market gardening (positively for onions and negatively for krinkrin) and gender (positively for pepper and negatively for krinkrin).

Only one of the fourteen tested variables significantly influences the simultaneous adoption of the five market garden crops: the presence of a village market, which has a negative effect. This implies that interviewed producers are more likely to adopt tomato, pepper, onions, krinkrin, and okra when there is no physical market near their villages.

Discussion

Increased market gardening production in southern Benin is now a reality, driven by projects, programs, strong grassroots support, and political will. However, this growth has not yet translated to year-round self-sufficiency. To address this, we believe that analyzing the choice of local market garden crops will be crucial in finding solutions.

Thus, the results reveal that in southern Benin, pepper is the most widely adopted market garden crop, followed by tomato. This result relating to adoption is not entirely in line with the national production data from the Directorate of Agricultural Statistics of the Ministry of Agriculture, Livestock and Fisheries, which specifies that over the last five years, the average production of tomato is 299,075 tons, while that of pepper is 117,080 tons

(DSA/MAEP, 2024). This qualifies our results to some extent in the sense that even if pepper is widely adopted in the south of Benin, the effect of this adoption is not sufficient to give a production of pepper higher than that of tomato. Our results do not deviate too much from those of Allogni *et al.* (2015), which demonstrated through a financial analysis that all chili production systems are profitable in southern Benin compared to others, which can clearly justify its adoption. In the same vein, Alinsato and Yagbedo (2018), recall the production areas in the south of Benin, notably the Adja plateau in the South-west, the South-east region and the peri-urban areas of Cotonou, Abomey-Calavi and Porto-Novo, as well as their characteristics confirm our conclusions.

The results indicate that pepper is the most widely adopted market garden crop in southern Benin, followed by tomato. This adoption pattern contrasts with national production data (DSA/MAEP, 2024) showing an average tomato production of 299,075 tons over the last five years, compared to 117,080 tons for pepper. This suggests that while pepper adoption is high in the south, its impact on overall production is not yet greater than that of tomato. Our findings align with Allogni et al. (2015), whose financial analysis demonstrated the profitability of all chili production systems in southern Benin, potentially explaining its adoption rate. Similarly, Alinsato and Yagbedo (2018) identified key production areas in southern Benin (Adja plateau, South-east, and peri-urban Cotonou-Abomey-Calavi-Porto-Novo) and their characteristics support our conclusions.

Furthermore, the presence of a village market is the sole factor negatively influencing the simultaneous adoption of all studied crops. Specifically, interviewed producers tend to adopt more tomato, pepper, onions, krinkrin, and okra when a physical market is not located near their villages. This seemingly paradoxical finding contrasts with Fayolle et al. (2008) and Robast et al. (2006), who emphasize the role of physical markets in integrating market gardeners into formal distribution channels, thereby improving product quality and traceability. However, our results are qualified by the context of southern Benin, characterized by relatively short distances to sales markets, notably the large Dantokpa market in Cotonou. In this context, the absence of a local market may not be a significant impediment, especially as producers often target more profitable urban markets. The Dantokpa market exemplifies the importance of physical markets as central hubs for local agricultural product sales, directly contributing to the food supply of major cities like Abomey-Calavi, Cotonou, and Porto-Novo.

Moreover, our findings indicate that education level positively influences the adoption of at least one of the five market garden crops. This aligns with previous research showing a direct impact of education on producers' ability to adopt improved production techniques. As Tchouamo et

al. (2005) noted, more educated producers are more likely to use modern farming methods, enhancing the productivity and sustainability of their vegetable farms. Similarly, educated farmers tend to have a better grasp of market dynamics and are better equipped to manage risks in vegetable production (Fofana et al., 2010).

Our findings also confirm that the presence of a telephone network positively influences the adoption of at least one of the five market garden crops. As highlighted in the literature, an efficient telephone network significantly aids agricultural production by improving communication among producers, suppliers, and markets. Sassi and Goaied (2013) note that access to a telephone network enables farmers to obtain timely information on market prices, weather, and new farming techniques, thus optimizing their decision-making. Additionally, Duflo et al. (2012) emphasize that mobile telephony reduces risks associated with market uncertainty and enhances the profitability of market gardening by optimizing supply chains. This same positive effect and interpretation apply to the presence of a market gardening promotion structure near producers.

Our data analysis also reveals a negative influence of farm management tool usage on the adoption of at least one of the five market garden crops. While seemingly counterintuitive, this finding is understandable given the recent introduction of these tools in market gardening in our context. Gathigi (2011) similarly found that the introduction of complex management tools can impede the adoption of new agricultural practices due to integration challenges with traditional systems and insufficient producer training. Likewise, Tchouamo et al. (2005) noted that farm management technologies can sometimes lead to information overload and increased administrative burden, potentially discouraging some producers.

What's more, our research shows that the type of area, specifically its proximity to the water table, positively influences the adoption of at least one of the five market garden crops. Indeed, easy access to groundwater due to a shallow water table allows producers to ensure stable and continuous irrigation, crucial for market garden production and thus favoring its adoption. Duflo et al. (2012) similarly highlight the significant advantage for market gardeners in areas near water tables, as it ensures good water availability and reduces reliance on climatic conditions. As well, Tallet (1983) argues that irrigation facilitated by proximity to the water table is a key factor for market gardening adoption, especially in semi-arid regions where groundwater access enables stable and regular production.

The results also demonstrate that site security positively influences the adoption of at least one of the five market garden crops. According to Wanyama et al. (2019), securing farm sites is a key factor in the adoption of market gardening, as it allows producers to reduce land tenure risks and focus

on medium- and long-term investments in agricultural infrastructure such as irrigation and fertilization. Kouadio et al. (2014) indicate that securing sites, particularly through clear land policies and sustainable land management systems, plays a key role in stimulating the adoption of market gardening crops, as it provides producers with a stable environment to cultivate and increase their productivity. Clearly, securing land tenure is a central element that positively influences adoption, by guaranteeing producers sustainable access to land, which encourages them to invest in modern agricultural practices and adopt intensive crops (Bationo et al., 2010).

A seemingly ambiguous finding in our study is that professional experience positively influences onion adoption while negatively affecting krinkrin adoption. Similarly, gender positively influences pepper adoption but negatively impacts krinkrin adoption. For onions and pepper, experienced producers likely better identify favorable growing conditions and apply more efficient irrigation and fertilization methods, thus improving profitability (Duteurtre, 2006). This aligns with Koffi and Oura (2019), who suggest that professional experience generally fosters the adoption of innovative agricultural practices. For instance, strengthening onion producers' technical and organizational capacities is crucial (David-Benz & Seck, 2018). The negative influence on krinkrin adoption by both experience and gender could be attributed to experienced producers' preference for more profitable and established crops like onion and chili, potentially viewing lesser-known crops like krinkrin as less lucrative or riskier. In essence, experienced producers, having mastered popular and profitable crops like chili and onion, are hesitant to diversify with less conventional options (Sassi & Goaied, 2013; Tchouamo et al., 2005).

Conclusion

This study used a multivariate probit model to analyze the factors that determine the adoption of local crops, including tomato, pepper, onions, krinkrin and okra in southern Benin, in order to contribute to the scientific debate on the determinants of adoption. The results revealed adoption rates of 78.48% for pepper, 49.58% for tomato, 39.87% for okra, 31.43% for krinkrin and 17.93% for onions. The results also revealed the existence of interdependence in the adoption of the different local vegetable crops studied. The decision to adopt a local vegetable crop is determined by the adoption of another local vegetable crop and vice versa. Overall, the majority of producers surveyed prefer to adopt a combination of two crops at a time (27.43%) or four crops at a time (25.74%). The results of the study also revealed that the existence of a market in the village, the level of education, the existence of a telephone network, the type of area in relation to the proximity or not of the water table and the security of the sites are the main factors determining the

adoption of local market gardening crops. Based on these empirical results, the study proposes that agricultural policies aimed at promoting market gardening crops should be oriented towards supporting the creation of inter-professional organizations, the harmonious organization of market gardening production according to agricultural development centers and then the creation of infrastructure and equipment to make fresh market garden produce available in all seasons.

This study employed a multivariate probit model to analyze the determinants of local crop adoption (tomato, pepper, onions, krinkrin, and okra) in southern Benin, contributing to the scientific discourse on adoption factors. The findings revealed the following adoption rates: pepper (78.48%), tomato (49.58%), okra (39.87%), krinkrin (31.43%) and onions (17.93%). Notably, the adoption of these local vegetable crops showed interdependence, with the decision to adopt one influencing the adoption of others. Most surveyed producers favored adopting two (27.43%) or four (25.74%) crops simultaneously. Key factors influencing local market gardening crop adoption were identified as the presence of a village market, education level, telephone network availability, proximity to the water table, and site security. Based on these results, the study recommends that agricultural policies promoting market gardening should focus on supporting inter-professional organizations, harmonizing production according to agricultural development centers and developing infrastructure and equipment for year-round availability of fresh produce.

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L'impact de l'attachement au lieu sur l'intention comportementale des touristes: revisiter et recommander la destination d'Agadir

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Résumé

Cette étude s'inscrit dans le champ des recherches sur le comportement du consommateur appliquées au tourisme, en explorant le rôle de l'attachement au lieu dans la formation de l'intention comportementale des touristes. L'objectif principal est d'évaluer l'influence de cet attachement sur deux dimensions clés : l'intention de revisiter et celle de recommander la destination. Un modèle théorique a été développé et testé empiriquement à l'aide de la modélisation par équations structurelles (SEM), sur la base de données recueillies auprès d'un échantillon de visiteurs. Les résultats empiriques confirment que l'attachement au lieu constitue un déterminant significatif et positif de l'intention comportementale. Ces résultats mettent en évidence l'importance des variables affectives dans le processus décisionnel post-visite. Les implications de ces constats sont notables pour la gestion des destinations touristiques, notamment en matière de stratégies de fidélisation et d'amélioration de l'expérience visiteur. En conclusion, cette recherche souligne la nécessité d'intégrer les dimensions émotionnelles dans la conception des politiques de marketing territorial.

The Impact of Place Attachment on Tourists' Behavioral Intention: Revisiting and Recommending Agadir

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Abstract

This study contributes to the field of consumer behavior in tourism by examining the influence of place attachment on tourists' behavioral intentions. Specifically, it investigates how emotional bonds with a destination affect two key outcomes: the intention to revisit and the intention to recommend the destination. A conceptual model was developed and empirically tested using structural equation modeling (SEM), based on data collected from a sample of visitors. The findings confirm that place attachment is a significant and positive predictor of both revisit and recommendation intentions. These results underscore the critical role of affective factors in post-visit decision-making. The study offers valuable insights for destination management, particularly in enhancing visitor loyalty and improving the overall tourist experience. Ultimately, the research highlights the importance of incorporating emotional dimensions into territorial marketing strategies.

Keywords: Place attachment, behavioral intention, destination attachment, intention to revisit, intention to recommend

Introduction

Le comportement touristique se déroule en trois étapes clés : avant la visite, pendant la visite et après la visite (Rayan, 2002 ; William et Buswell, 2003). Ces phases reflètent l'évolution des attentes et des expériences des touristes, influençant ainsi leurs intentions comportementales futures. Chen et Tsai (2007) ont souligné que ce processus inclut le choix de la destination et l'évaluation de l'expérience par les touristes, laquelle peut aboutir à la confirmation ou à la non-confirmation de leurs attentes, ainsi qu'à la formation de leur intention comportementale future. Il englobe également la probabilité de revisiter une destination et de la recommander à d'autres (Som et al., 2012). L'intention comportementale, selon de nombreuses études, se révèle être un indicateur fiable du comportement futur des touristes. En effet, lorsque cette intention est mesurée de manière adéquate, elle permet de prédire

efficacement les actions futures des visiteurs (Lin, 2014). L'intention de revisiter et de recommander une destination constitue un élément essentiel influençant la fidélité des touristes et, par conséquent, la pérennité du succès d'une destination. Ce processus est particulièrement influencé par l'attachement au lieu, une dimension émotionnelle qui peut renforcer ces intentions.

Ainsi, cette étude s'intéresse à l'effet de l'attachement au lieu sur les intentions comportementales des touristes, notamment l'intention de revisiter et de recommander une destination. Comprendre cette relation est essentiel pour les gestionnaires de destinations touristiques, car cela permet de mieux cerner les facteurs affectifs qui influencent les choix et les comportements des visiteurs.

L'attachement au lieu

L'attachement au lieu désigne le lien émotionnel et psychologique qu'un individu établit avec un lieu spécifique, influencé par ses expériences et interactions dans cet environnement. Ce concept, lié à la théorie de l'attachement de Bowlby (1969), est multidimensionnel, impliquant des aspects affectifs, cognitifs et sociaux. Il peut être perçu comme une extension du soi, où le lieu devient une partie de l'identité personnelle (Belk, 1992). Ce lien affectif se construit à travers des interactions positives et des expériences vécues, renforçant ainsi le sentiment de sécurité et d'appartenance (Low & Altman, 1992 ; Williams & Vaske, 2003).

Les dimensions de l'attachement au lieu

Plusieurs recherches ont cherché à appréhender et à conceptualiser l'attachement au lieu, donnant ainsi naissance à une variété de modèles et d'échelles de mesure. Cependant, les auteurs divergent quant aux dimensions de l'attachement au lieu : certains le conçoivent comme un modèle bidimensionnel ou tridimensionnel, tandis que d'autres l'envisagent comme un processus dynamique. Dans cette étude, nous nous focalisons sur l'exemple quadridimensionnel, considéré comme le plus utilisé dans la littérature.

L'identité au lieu

L'identité du lieu est un concept qui désigne le lien entre un individu et un espace spécifique, un lien si fort que le lieu devient intrinsèquement lié à l'identité personnelle de l'individu (Proshansky, 1978). Ce lien repose principalement sur des éléments cognitifs et affectifs, et constitue une sous-structure de l'identité de soi, façonnée par l'interaction entre l'individu et son environnement physique (Proshansky et al., 1983). L'identité de lieu est souvent décrite comme une « base de données » mentale, composée de souvenirs, de conceptions, de valeurs et de sentiments associés à un lieu

particulier (Proshansky et al., 1983). Divers chercheurs ont élargi ce concept, soulignant que l'identité de lieu inclut des dimensions personnelles, physiques, sociales et culturelles, allant des caractéristiques environnementales aux éléments sociaux comme le statut et le mode de vie (Marzano, 2015). Elle peut aussi engendrer des divergences entre groupes au sein d'une même communauté, en fonction des perceptions et des significations attribuées au lieu. En somme, l'identité du lieu est façonnée par l'expérience personnelle et collective d'un endroit, permettant à un individu de s'y identifier et d'exprimer son sentiment d'appartenance. Elle intègre une interaction entre l'individu et les caractéristiques physiques, sociales et culturelles d'un lieu, créant ainsi une relation unique et personnelle avec cet espace (Feldman, 1990 ; Scannell et Gifford, 2010).

La dépendance au lieu

L'attachement au lieu comprend une dimension essentielle : celle de la dépendance au lieu, considérée comme cruciale pour la réalisation des objectifs spécifiques des individus (Ramkissoon, 2015a). Cette dimension est souvent vue comme un attachement fonctionnel, où le lieu est valorisé en raison des activités qu'il soutient ou facilite (Stokols et Shumaker, 1981). Elle sert d'outil pour mesurer l'authenticité, la satisfaction et l'attachement au lieu (Ramkissoon, 2015a). La dépendance au lieu est un type d'attachement où les individus évaluent un lieu en fonction de sa capacité à répondre à leurs besoins spécifiques (Jorgensen et Stedman, 2001 ; Moore et Graefe, 1994). Elle se rapporte à la capacité du lieu à soutenir les objectifs et activités de l'individu, avec une importance accordée à la manière dont le lieu peut répondre à ses besoins particuliers (Stokols et Shumaker, 1981 ; Williams et Roggenbuck, 1989).

Le lien social au lieu

Le lien social se concentre sur le contexte social qui associe les individus au paysage physique et culturel du lieu (Buta et al., 2014 ; Kyle et al., 2004). De nombreuses études ont montré l'influence des liens sociaux sur le développement de l'attachement affectif à un lieu (Lewicka, 2005 ; Fried, 2000 ; Pretty et al., 2003). Les liens sociaux contribuent au sentiment de « chez-soi » dans un quartier, renforçant l'appartenance au lieu à mesure que les individus établissent des relations avec leur environnement local (Moser et al., 2002). Fried (2000) considère cette dimension relationnelle comme essentielle pour l'attachement au lieu, en la situant dans le cadre de l'environnement social. De plus, la présence de relations amicales dans l'environnement local est un facteur clé renforçant l'attachement au lieu (Pretty et al., 2003).

L'affect au lieu

L'affect est une composante essentielle de l'attachement au lieu, souvent décrit comme les liens émotionnels qu'un individu entretient avec un lieu spécifique (Low et Altman, 1992 ; Ramkissoon et al., 2012 ; Halpenny, 2010). Il est associé à un sentiment de bien-être et à un investissement émotionnel dans les lieux (Pellow, 1992 ; Hummon, 1992). L'intensité de ces liens affectifs est généralement mesurée par le nombre d'expériences vécues dans un lieu.

Par exemple, les amateurs d'environnements naturels, ayant accumulé des expériences avec ces lieux, tendent à développer des liens affectifs plus forts (Ramkissoon et al., 2013a, 2013b ; Hinds et Sparks, 2008). Ces expériences successives favorisent un sentiment de confort et de bien-être, renforçant le sens du lieu (Rollero et De Piccoli, 2010 ; Tuan, 1977). L'attachement au lieu est un lien positif et affectif entre l'individu et un lieu spécifique, comme le confirment Hernandez et al. (2001, 2007). Les humains forment des liens affectifs avec des lieux qu'ils considèrent comme importants dans leur vie. Ces liens varient selon le type de lieu, qu'il s'agisse d'une ville, d'un lieu de loisir ou d'un quartier (Hammitt et al., 2006 ; Hay, 1998b ; Altman et Low, 1992).

L'intention comportementale :

Au cours de la dernière décennie, la notion d'intention comportementale a suscité un intérêt croissant dans la littérature touristique (Baker et Crompton, 2000 ; Sparks, 2007). De manière générale, elle est définie comme la propension subjective d'un individu à adopter un comportement donné (Fishbein et Ajzen, 1975). Dans le domaine du tourisme, les intentions comportementales sont considérées comme des prédicteurs essentiels des comportements réels des visiteurs (Kozak, 2001). Sheeran (2002) souligne d'ailleurs que ces intentions ont été largement mobilisées pour anticiper divers comportements de consommation. Par ailleurs, l'intention d'adopter un comportement a été intégrée et interprétée à travers plusieurs cadres théoriques (Soliman, 2019).

Parmi ces cadres, la théorie du comportement planifié (Theory of Planned Behavior – TPB) figure parmi les plus influentes et les plus utilisées pour expliquer et prédire les intentions comportementales (Fielding et al., 2008). Selon cette théorie, l'intention représente le facteur immédiat déterminant la réalisation d'un comportement donné (Ajzen, 1985). Cette intention résulte de trois composantes majeures : l'attitude à l'égard du comportement, les normes subjectives et le contrôle comportemental perçu (Ajzen, 1985, 1991 ; Lam et Hsu, 2004).

L'attitude se réfère aux évaluations positives ou négatives qu'un individu associe à l'exécution d'un comportement spécifique. Elle émerge des

croyances fondamentales relatives aux conséquences de ce comportement, ainsi que de l'évaluation de ces conséquences (Ajzen et Fishbein, 1980 ; Kim et Han, 2010). Ainsi, les individus peuvent développer des attitudes favorables ou défavorables envers un comportement, influençant directement leur intention d'agir (Bianchi et al., 2017).

Dans le contexte touristique, l'attitude des touristes est généralement appréhendée à travers trois composantes : cognitive, affective et comportementale. La composante cognitive concerne l'évaluation rationnelle qui fonde la formation des attitudes ; la composante affective reflète les réactions émotionnelles du touriste, traduisant sa préférence pour une destination ; enfin, la composante comportementale exprime l'intention ou la propension du touriste à visiter (ou revisiter) ladite destination (Lee, 2009).

L'intention de recommander

L'intention peut être définie comme la disposition à entreprendre une action planifiée dans le futur. Elle reflète la probabilité qu'un individu traduise ses attitudes ou croyances en comportements concrets. À ce titre, elle constitue un prédicteur pertinent des comportements effectifs (Kozak, 2001). Whyte (1954) conceptualise l'intention de recommandation comme une forme de communication interpersonnelle, relevant du bouche-à-oreille, entre deux individus ou plus. Cette intention est perçue comme un vecteur d'influence sociale au sein des relations interpersonnelles. Plusieurs chercheurs l'identifient comme un indicateur de la performance organisationnelle (Reichheld, 2003 ; Keiningham et al., 2007b ; Morgan et Rego, 2006).

Selon Kim et Kim (2010), l'intention de recommandation relève d'un comportement psychologique, orienté vers la transmission d'informations essentiellement positives à autrui. Ce comportement découle souvent d'expériences personnelles ou d'échanges d'informations au sein du cercle familial, amical ou social. Kang et al. (2017) soulignent quant à eux la complexité du processus décisionnel, qui dépasse la simple décision d'achat. Il s'agit d'un enchaînement de phases incluant l'évaluation post-achat de l'expérience de consommation, à travers la satisfaction ou l'insatisfaction perçue. Ce processus peut conduire à des comportements de fidélisation, tels que l'achat répété, ainsi qu'à la diffusion d'un bouche-à-oreille positif.

L'intention de revisiter

La recherche scientifique en tourisme accorde une attention croissante à l'analyse des intentions comportementales des touristes, en particulier à l'intention de revisite (Lam et Hsu, 2006 ; Qu, 2017 ; Ramukumba, 2018 ; Um et al., 2006). Ces intentions traduisent l'évaluation, par les individus, de leur intérêt pour un produit ou un service, ainsi que l'estimation de la probabilité d'un comportement d'achat effectif (Han et Ryu, 2007 ; Oliver, 1997).

L'intention de revisite a fait l'objet de multiples conceptualisations. Baker et Crompton (2000) la définissent comme la probabilité pour un touriste de répéter une activité ou de retourner dans une destination donnée. Elle renvoie à la volonté explicite de revisiter un lieu déjà expérimenté (Cole et Scott, 2004 ; Qu, 2017). Pour Chang et al. (2014), elle représente le comportement anticipé relatif à un voyage futur. Plusieurs auteurs (Baker et Crompton, 2000 ; Sparks, 2007 ; Li et al., 2010 ; Um et al., 2006 ; Fishbein et Ajzen, 1975) reconnaissent l'intention comportementale comme un indicateur fiable du comportement futur. En effet, lorsque cette intention est mesurée de manière rigoureuse, elle permet une prédiction efficace du comportement réel des touristes (Lin, 2013).

Enfin, Weaver et Lawton (2011) décrivent l'intention de revisite comme un état cognitif traduisant le projet d'un touriste de revenir dans une destination spécifique dans un laps de temps donné. Il s'agit d'un construit central dans le champ du marketing touristique, en tant que levier de prévision des comportements futurs (Chen et al., 2020).

La relation entre l'intention comportementale et l'Attachement au lieu
L'intention de recommander et l'attachement au lieu
L'attachement au lieu est très convoité dans les études en tourisme, afin d'explorer les attachements émotionnels, fonctionnels, affectifs et sociaux des touristes aux destinations touristiques et/ou aux produits touristiques (Brown et al., 2016 ; Ramkissoon et Mavondo, 2015 ; Xu et Zhang, 2016 ; Yuksel et al., 2010). D'ailleurs, de nombreuses études ont confirmé que l'attachement au lieu affecte les diverses intentions comportementales futures telles que le WOM (Chen et al., 2014 ; Zenker et Rutter, 2014) et l'intention de recommandation d'une destination (Hosany et al., 2017 ; Liu et al., 2019 ; Loureiro, 2014 ; Prayag et Ryan, 2012 ; Tsai, 2016) (Cf. figure 1).

Figure 1: Les dimensions de l'attachement au lieu
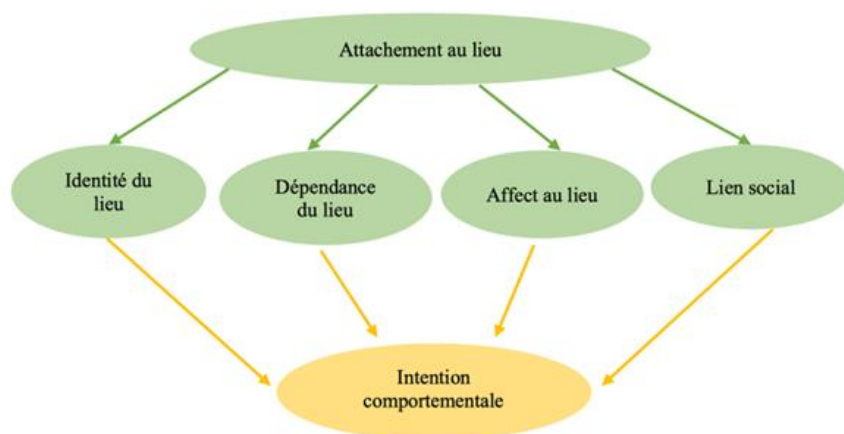
Source : Adapté de Ramkissoon, (2015a)

Zhang et al. (2019) ont soutenu des études antérieures qui ont mis en évidence le lien entre l'attachement au lieu et l'intention de recommander. Nous citons l'exemple de Lee et al. (2012), qui stipulent que la dépendance au lieu prédit le bouche-à-oreille positif.

Park et al. (2008) ont abordé l'importance de l'attachement dans la promotion d'une marque. De plus, Prayag et Ryan (2012) ont pu affirmer que deux dimensions de l'attachement - « l'identité du lieu » et « la dépendance au lieu » - prédisent l'intention de recommander. Selon Zhang et al. (2019), un attachement fonctionnel (dépendance au lieu) au lieu du festival renforce l'intention des visiteurs de revisiter et de recommander le festival. Les visiteurs attachés au lieu (ville ou pays) sont plus susceptibles de le recommander à leur famille, amis et autres.

L'intention de revisiter et l'attachement au lieu

L'intention de revisiter est identifiée comme la détermination des individus de revisiter le même lieu à maintes reprises et de le recommander à d'autres individus (Su et al., 2011). Pour comprendre le processus de constitution de l'intention de revisiter, certains auteurs ont soulevé des variables qui peuvent l'influencer, telles que la satisfaction client (Al-alak et El-refae, 2012), la fidélité client (Kim et al., 2015), l'attitude (Jung et al., 2014), la qualité du service (Chen et Chen, 2007), le motif de participation (Chang et al., 2014), les expériences émotionnelles (Wirtz et Bateson, 1999) et l'attachement au lieu (Lee et Shen, 2013). Ainsi, l'attachement au lieu est considéré comme au cœur des intentions comportementales des touristes (Lee et Shen, 2013 ; Neuvonen et al., 2010 ; Petrick, 2004 ; Prayag et Ryan, 2012). Dans cette optique, l'attachement au lieu est adopté dans la prédiction des phénomènes comportementaux et conatifs (Lee et al., 2007). Il s'est révélé être à la fois un antécédent (Hwang et al., 2005 ; Yuksel et al., 2010) et une conséquence (Gross et Brown, 2008 ; Kyle et al., 2004 ; Rollero et Piccoli, 2010) des attitudes et des intentions de revisiter. Quatre mesures d'attachement au lieu ont été documentées : l'identité au lieu, la dépendance au lieu, l'affectivité au lieu et le lien social au lieu (Jorgensen et Stedman, 2001 ; Williams et al., 1992).

- L'intention de revisiter et l'identité du lieu

L'identité du lieu reflète la liaison entre un individu et un lieu ou un environnement physique (Isa et al., 2019). Plusieurs recherches ont examiné le lien entre l'identité de lieu et l'intention de revisiter (George et George, 2004 ; Prayag et Ryan, 2012). Ils ont positionné l'identité de lieu comme une variable médiatrice entre l'expérience passée et l'intention de revisiter (Isa et al., 2019), ainsi que pour la satisfaction et la fidélité des touristes. Ainsi, Kil

et al. (2012) exposent l'identité du lieu comme un médiateur important dans les visites futures et les intentions de revisite.

- <u>L'intention de revisiter et la dépendance au lieu</u>

La dépendance au lieu fait souvent référence à la concordance entre un lieu et l'atteinte d'un objectif au sein de ce lieu (Jorgensen et Stedman, 2001). La dépendance au lieu a une influence directe sur les intentions de revisite des touristes (Chiang, 2016 ; Loureiro, 2014). En effet, de nombreuses études ont confirmé que la dépendance au lieu joue un rôle dans la constitution des intentions de revisite (Kaplanidou et al., 2012 ; Lee et al., 2012 ; Tsai, 2016). Une étude sur le tourisme rural a mentionné que la dépendance au lieu avait une influence positive sur les intentions et les recommandations de revisite chez les touristes ruraux (Loureiro, 2014).

- <u>L'intention de revisiter et lieu affectif</u>

Le lieu affectif représente la relation entre le lien émotionnel et un cadre particulier (Bagozzi et al., 1999 ; Jorgensen et Stedman, 2001). Il existe un nombre considérable d'auteurs qui stipulent que le lieu affectif a des répercussions sur les visites répétées dans une destination (Cheng et Lu, 2013 ; Kil et al., 2012 ; Su et al., 2011). De même, des études ont affirmé que le lieu affectif (c'est-à-dire le plaisir, l'hédonisme, les valeurs affectives) influence positivement les intentions de revisiter et de recommander (Hanzaee et Rezaeyeh, 2013 ; de Oliveira Santini et al., 2018). À l'exception près, Yuksel et al. (2010) ont constaté que le lien entre la satisfaction et l'affection du lieu est plus fort que le lien entre l'affectif du lieu et la loyauté concernant l'intention de revisiter.

- <u>L'intention de revisiter et le lien social du lieu</u>

Le lien social du lieu est assimilé aux interactions sociales des relations interpersonnelles, communautaires et culturelles où les gens ont un attachement (Low et Altman, 1992). Le lien social du lieu constitue une dimension cruciale dans le processus de revisite des destinations touristiques (Buonincontri et al., 2017 ; Neuvonen et al., 2010 ; Rajesh, 2013). Ramkissoon et Mavondo (2015) attestent que les liens sociaux ont une influence positive sur la satisfaction du lieu et peuvent prédire les intentions de revisite des touristes. Cependant, les touristes qui nouent un lien social avec des amis et des familles parviennent à maintenir leur identité culturelle et leurs intentions de revisiter (Lee et al., 2014).

Hypothèse et modèle conceptuel

Face à la pénurie de recherches empiriques sur la relation entre l'attachement à la destination et l'intention comportementale (la recommandation et la revisite), nous avons choisi de nous appuyer sur un raisonnement théorique pour explorer cette dynamique. En l'absence d'une base empirique solide, il est essentiel de proposer un cadre conceptuel robuste. Ainsi, nous avons sélectionné un modèle quadridimensionnel de l'attachement au lieu pour étudier cette relation, un modèle qui regroupe quatre dimensions fondamentales : l'identité au lieu, la dépendance au lieu, l'affect au lieu et le lien social. Ces dimensions permettent de mieux comprendre comment l'attachement à une destination influence l'intention des touristes à revisiter un lieu et à le recommander aux autres.

Le choix du modèle quadridimensionnel

Le modèle quadridimensionnel de l'attachement au lieu, que nous avons retenu, offre une vision nuancée de l'attachement à la destination. Chaque dimensions s'avère crucial pour comprendre comment les touristes établissent des liens avec une destination et comment ces liens influencent leur intention de revisiter ou de recommander cette destination.

Collecte des items et sous-items

Afin de mesurer de manière détaillée ces quatre dimensions, nous avons collecté un ensemble d'items et de sous-items issus de la littérature existante. Ces items servent à évaluer l'attachement à la destination et à relier cet attachement à l'intention comportementale (revisiter et recommander une destination). Il est important de préciser que l'ensemble des items développés pour cette recherche provient majoritairement de la littérature.

En résumé, à travers la littérature, nous avons collecté un ensemble d'items et de sous-items qui nous permettent de mesurer l'attachement à la destination selon un modèle quadridimensionnel. L'ensemble des items développés dans cette recherche repose sur les travaux d'auteurs clés dans le domaine, ce qui permet de garantir la pertinence et la validité de l'approche. L'impact de ces dimensions sur l'intention de revisiter et de recommander une destination sera ensuite étudié pour éclairer les implications pratiques de l'attachement à la destination dans le contexte touristique.

Figure 2 : Modèle conceptuel de recherche
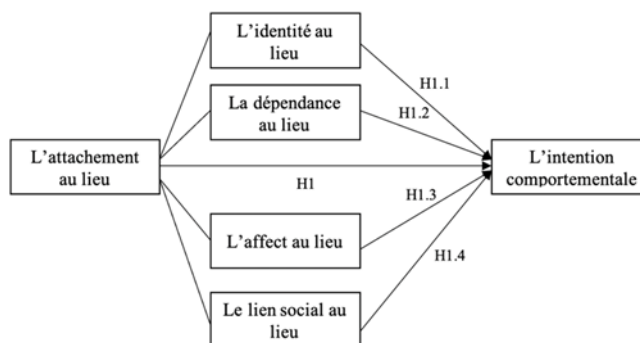
Source : Auteur

L'analyse du modèle conceptuel a permis d'identifier et d'expliquer les variables déterminantes de l'intention comportementale des visiteurs au sein de la destination d'Agadir. Cette analyse a mis en lumière les différents facteurs liés à l'attachement au lieu qui influencent les comportements des touristes, notamment leur intention de revisiter la destination ainsi que leur intention de la recommander à d'autres personnes.

L'étude de ces relations nous amène à postuler l'existence de relations de causalité directes entre les dimensions de l'attachement au lieu et l'intention comportementale des touristes.

Ces relations de causalité directe constituent le fondement des hypothèses de la recherche, qui visent à valider la structure causale du modèle. L'hypothèse principale postule que l'attachement au lieu influence l'intention comportementale. Cette structure causale sera testée à travers l'analyse des données collectées sur le terrain, permettant ainsi de confirmer ou d'infirmer les relations théoriques proposées dans le modèle. L'objectif est de démontrer que l'intensité de l'attachement des touristes à la destination d'Agadir est un facteur clé déterminant leur intention comportementale, et ce, à travers des liens directs entre les dimensions de l'attachement et les intentions de revisite et de recommandation.

Ainsi, au niveau de cette étude la relation est vérifiée à travers la formulation des hypothèses ci-dessus :

- o H1 : « L'attachement au lieu influencerait l'intention comportementale » Les sous hypothèses sont décrites comme suit : H1-1 : « L'identité au lieu aurait un effet sur l'intention de revisiter et de recommander »
- o H1-2 : « La dépendance aurait un effet sur l'intention de revisiter et de recommander »
- o H1-3 : « L'affect aurait un effet sur l'intention de revisiter et de recommander »
- o H1-4 : « Le lien social aurait un effet sur l'intention de revisiter et de recommander »

Méthodologie de l'étude empirique :

La triangulation entre la revue de littérature, le cadre théorique et les hypothèses de recherche a permis l'élaboration d'un modèle conceptuel, lequel a été vérifié empiriquement à travers une étude quantitative.

Dans le cadre de toute étude empirique quantitative, il est essentiel de définir clairement la population cible afin de tester la validité des hypothèses théoriques (Royer et Zarlowski, 2003). Ainsi, l'échantillon de cette étude se compose de 292 touristes ayant visité Agadir à des fins de vacances et de loisirs. La répartition par sexe des répondants est la suivante : 46,60 % de femmes et 53,40 % d'hommes.

Un examen plus approfondi de la provenance géographique des participants révèle une dominance des touristes français (28,7 %), suivis des touristes britanniques (14,04 %), puis des touristes allemands (8,90 %). Les touristes espagnols, belges, danois et finlandais représentent respectivement 5,82 %, 5,47 %, 5,13 % et 5,13 % de l'échantillon. Les touristes en provenance des pays du Moyen-Orient sont également bien représentés, notamment la Chine (4,79 %), le Canada (4,45 %), et l'Australie (4,10 %), tandis que les autres nationalités varient entre 1,02 % et 3,42 %.

Il a également été pertinent d'analyser deux aspects concernant la durée de fréquentation et la fréquence des visites à la destination d'Agadir. Il a été observé que 38,4 % des répondants fréquentent la destination depuis plus de 10 ans, 13,7 % depuis un an, et 12,6 % depuis environ trois ans. En ce qui concerne la fréquence des visites, 34,2 % des participants se rendent à Agadir chaque année, 34,2 % tous les deux ans, et 16,4 % tous les six mois.

Pour la collecte des données, le questionnaire a utilisé une échelle de Likert à sept points, permettant ainsi une mesure fine des opinions et perceptions des répondants.

Résultats
Analyse factorielle exploratoire

Dans cette phase empirique, nous effectuons une évaluation du modèle interne, y compris la vérification de la validité convergente et de la validité discriminante. Ensuite, nous introduisons l'évaluation externe du modèle visant à tester les hypothèses de recherche, en vérifiant l'importance des relations causales entre les variables latentes. Nous en cheminons par un contrôle de la qualité du modèle, en utilisant le test d'adéquation (note GoF). L'analyse se termine par l'interprétation et la discussion des résultats du test de validité des hypothèses formulées qui peuvent être confirmées ou infirmées.

La modélisation par les équations structurelles à variables latentes basée sur la méthode PLS

La modélisation par équations structurelles selon la méthode PLS, suppose l'application d'une procédure constituée de quatre étapes pour évaluer le modèle de mesure (Esposito-Vinzi, Trinchera et Amato, 2010, Tenenhaus et Esposito-Vinzi, 2005) à savoir :

a) Évaluation de la fiabilité : à travers Alpha de Cronbach et le rho de Dillon-Goldstein qui doivent être supérieurs ou égaux à 0.7

b) Vérification de l'unidimensionnalité : on utilise les valeurs propres issues de l'analyse en composantes principales, la première doit être supérieure à 1 et les suivantes inférieures à 1. On vérifie également que les variables manifestes sont davantage corrélées avec la variable latente qu'elles sont censées mesurer qu'avec les autres.

c) Évaluation de la validité convergente : examen des corrélations (*loading factors*) des items avec leur variable latente qui doivent être supérieures à 0.7

d) Évaluation de la validité discriminante : chaque variable latente doit être liée plus fortement à ses indicateurs qu'aux autres variables latentes du modèle. Cela est le cas lorsque la corrélation au carré entre 2 variables latentes est inférieure aux index AVE (variance extraite moyenne) de chaque variable latente aussi appelée communalité moyenne (Tenhenhaus et al., 2005). Chin (1998) préconise que l'AVE ait une valeur supérieure ou égale à 0.5

L'évaluation du modèle de mesure à travers la méthode PLS

La qualité du modèle de mesure (*outer model*) représentant les relations linéaires entre variables latentes et variables manifestes, est évaluée suivant trois critères à savoir : la fiabilité des échelles de mesure, la validité convergente et la validité discriminante.

Nous présenterons tout d'abord notre modèle de mesure avant ajustement. Puis, nous procéderons à l'analyse de fiabilité des échelles de mesure, et nous présenterons notre modèle de mesure après ajustement. Ensuite, nous testerons la validité convergente de notre modèle de mesure, et finalement sa validité discriminante. Nous enchainerons avec l'évaluation globale de prédictivité de notre modèle de recherche à travers l'index de *Goodness of Fit* (GoF) (2.4)

Mesure de la fiabilité du modèle de mesure

Nous avons commencé par l'analyse de chaque item à travers l'examen des saturations (Loadings), ensuite nous avons procédé à l'évaluation de la fiabilité générale des construits.

La fiabilité des échelles de mesure est évaluée en utilisant l'Alpha de Cronbach. Le seuil admis par les chercheurs pour conclure qu'une échelle est fiable ou non est de 0,70.

Tableau 1: Loadings et Alpha de Cronbach sous PLS

Variables	Items	loadings	Alpha de Cronbach
Attachement 1	ATT_Affect_lieu1	0,974	**0,975**
	ATT_Affect_lieu2	0,975	
	ATT_Affect_lieu3	0,979	
Attachement 2	ATT_Dépendance_1	0,948	**0,925**
	ATT_Dépendance_2	0,950	
	ATT_Dépendance_3	0,899	
Attachement 3	ATT_Identité_1	0,968	**0,955**
	ATT_Identité_2	0,972	
	ATT_Identité_3	0,933	
Attachement 4	ATT_Lien_social1	0,963	**0,954**
	ATT_Lien_social2	0,956	
	ATT_Lien_social3	0,953	
Revisiter recommander	Revisiter_Recommander1	0,920	**0,955**
	Revisiter_Recommander2	0,953	
	Revisiter_Recommander3	0,906	
	Revisiter_Recommander4	0,886	
	Revisiter_Recommander5	0,941	
	Revisiter_Recommander6	0,818	

Source : Sortie du Smart PLS

Nous obtiendrons ainsi le modèle de mesure après ajustement comme présenté ci-dessous :

Figure 2 : modèle conceptuel de recherche
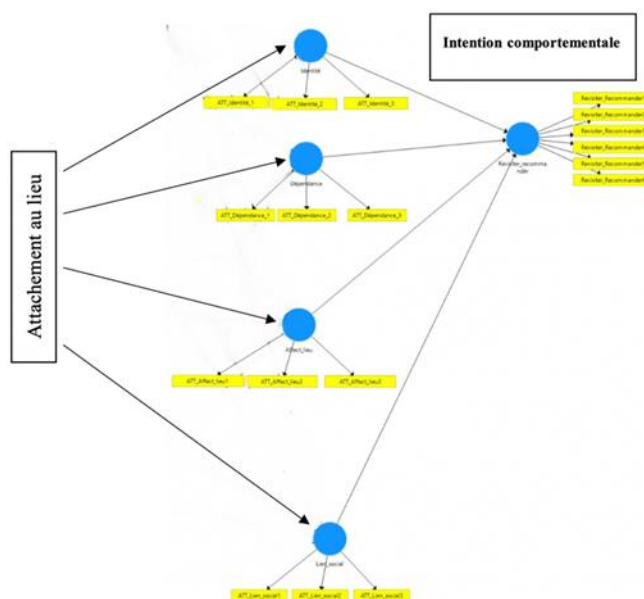
Source : Logiciel SPSS

La validité convergente

La validité convergente consiste à calculer la variance moyenne partagée entre un construit et ses items. L'utilisation de PLS permet de mesurer la validité convergente à travers: alpha de Cronbach et la consistance interne développés par Fornell et Larcker (1981).

L'interprétation des valeurs obtenues est similaire, ainsi la directive offerte par Nunnally (1978) peut être adoptée. Nunnally a considéré le seuil de 0.7 comme un record pour une fiabilité composée « modeste » (*composite reliability*) appliquée dans les stades de recherche antérieure.

Tableau 2: Signification et Fiabilité Composée (ρ) par construit

	Fiabilité composée
Affect au lieu	**0,984**
Dépendance au lieu	**0,952**
Identité au lieu	**0,971**
Lien social	**0,970**
Revisiter / recommander	**0,964**

Source : Sortie du Smart PLS

La validité discriminante

La validité discriminante est le complément méthodologique traditionnel de la validité convergente. Il représente l'étendu par lequel les indicateurs de mesure attribués aux variables latentes diffèrent-ils aux autres mesures des autres construits du modèle. La validité discriminante consiste à prouver que la variance partagée entre un construit et ses mesures (AVE) est supérieure à la variance partagée entre deux construits (r^2ij). Dans le contexte du PLS, le seul critère adéquat à la validité discriminante est que le construit doit plutôt partager la plus grande variance avec ses indicateurs de mesure qu'avec les autres construits.

Tableau 3: Validité discriminante

	Identité au lieu	Dépendance au lieu	Affect au lieu	Lien social au lieu	Revisiter_ recommander
Identité au lieu	**0,958**				
Dépendance au lieu	0,763	**0,933**			
Affect au lieu	0,840	0,839	**0,976**		
Lien social au lieu	0,809	0,761	0,797	**0,957**	
Revisiter_recommander	0,823	0,684	0,787	0,793	**0,905**

Source : Sortie du Smart PLS

La qualité globale du modèle de recherche : le test d'adéquation (GoF)

Généralement, la qualité du modèle de mesure est appréhendée par son pouvoir explicatif. Ce dernier est évalué par le coefficient de détermination (R^2) des variables endogènes.

Cet indice d'adéquation est obtenu sur la base de la moyenne des différents construits de la variance expliquée et R^2, l'indice de la redondance et de la communalité.

La redondance et R^2 ne sont pas calculés pour les construits exogènes. GoF est calculé par la formule Suivante :

$$GoF = \sqrt{(Moyenne\ (R^2))?\ (Moyenne\ (Communality))}$$

La valeur de l'indice GoF doit être supérieure à (0,30) puisque celle-ci représente le seuil limite recommandé.

Selon les résultats donnés, l'indice (ou l'index) de GoF est très satisfaisant : GoF = 0.71 (le seuil recommandé est 0.30).

Le test de validité du modèle structurel à travers la méthode PLS

Le modèle structurel représente les relations entre les variables latentes explicatives et les variables latentes expliquées.

Le test des hypothèses consiste tout d'abord à examiner le niveau de significativité des paramètres d'estimation (*path coefficient*) des relations entre les variables latentes. Une simulation de type *bootstrap* est réalisée à cet effet. Dans la perspective des recommandations de Chin (1998), nous avons utilisé la technique *bootstrapping* (avec un échantillon 292) afin de tester la significativité statistique de chaque coefficient.

Le tableau ci-dessous montrent les hypothèses, du path coefficients (Echantillon initial O), et la valeur T (O/STDEV), et la p-value qui doit être inférieur à 0.05 (*Cf.,* tableau 4).

Tableau 4: Estimation des paramètres du modèle causal par la méthode du Bootstrap

	Échantillon initial (O)	Valeur t (| O/STDEV |)	Valeur s-p	Significa tion
Identité_lieu -> Revisiter_recommander	0,418	2,856	0,004	Validée
Dépendance_lieu -> Revisiter_recommander	0,102	2,012	0,036	Validée
Affect_lieu -> Revisiter_Recommander	0,266	2,894	0,049	Validée
Lien social_lieu -> Revisiter_Recommander	0,320	2,355	0,019	Validée

Source : Élaboré par les auteurs d'après les sorties du logiciel Smart PLS

Le test des hypothèses relative aux conséquences de l'attachement sur l'intention comportementale

H1: « L'attachement au lieu influencerait l'intention comportementale »

H 1-1 : « L'identité au lieu aurait un effet sur l'intention de revisiter et de recommander »

Cette hypothèse est validée (p value= 0,004 < 0.05). Les estimations obtenues montrent une corrélation positive entre ces deux variables (β =0,418). L'examen de la valeur de t-value montre que cette dernière est égale à 2,856 (>1,96) ce qui implique une relation significative et positive entre les deux variables.

H 1-2 : « La dépendance aurait un effet sur l'intention de revisiter et de recommander »

Cette hypothèse est validée (p value= 0,036 < 0.05). Les estimations obtenues montrent une corrélation positive entre ces deux variables (β =0,102). L'examen de la valeur de t-value montre que cette dernière est égale à 2,012 >1,96) ce qui implique une relation significative et positive entre les deux variables.

H 1-3 : « L'affect aurait un effet sur l'intention de revisiter et de recommander »

Cette hypothèse est validée (p value= 0,049 < 0.05). Les estimations obtenues montrent une corrélation positive entre ces deux variables (β =0,266). L'examen de la valeur de t-value montre que cette dernière est égale à 2,894 (>1,96) ce qui implique une relation significative et positive entre les deux variables.

H 1-4 : « Le lien social aurait un effet sur l'intention de revisiter et de recommander »

Cette hypothèse est validée (p value= 0,019 < 0.05). Les estimations obtenues montrent une corrélation positive entre ces deux variables (β =0,320). L'examen de la valeur de t-value montre que cette dernière est égale à 2,355 (>1,96) ce qui implique une relation significative et positive entre les deux variables.

Tableau 5 : Tableau récapitulatif des principaux indices de mesure

Variable	Items	Nombre retenu	α	Variance	KMO	AVE	Fiabilité composite
$V_{1\ identité}$	- Je m'identifie fortement à la destination Agadir - Je ressens un fort sentiment d'appartenance envers la destination Agadir - Je sens que je suis réellement moi-même quand je suis dans la destination Agadir	3	0,975	91,787	0,741	0,918	0,971
$V_{2\ dépendance}$	- Aucun autre endroit ne peut se comparer à Agadir - Je reçois plus de satisfaction de visiter Agadir que n'importe quel autre endroit - J'aime beaucoup l'aménagement et la décoration de la destination Agadir	3	0,925	86,975	0,732	0,870	0,952
$V_{3\ affect}$	- La destination Agadir est très signifiante pour moi - Je ressens un fort sentiment d'appartenance à la destination Agadir et ses installations - J'ai un sentiment d'attachement émotionnel pour la destination Agadir et ses installations	3	0,955	95,270	0,784	0,953	0,984
$V_{4\ lien\ social}$	- J'ai des liens spéciaux avec les gens dans la destination Agadir - Les relations que j'ai à la destination Agadir sont importantes pour moi - Agadir un endroit préféré de la famille	3	0,954	91,633	0,775	0,916	0,970
$V_{5\ intention\ comportementale}$	- Je prévois de revisiter la destination Agadir dans les prochaines années - La probabilité que j'y retourne la prochaine fois est très élevée - Cette destination est mon premier choix de voyage - Je recommanderai cette destination à toute personne qui me demanderait conseil - J'encourage mes amis et mes proches à aller visiter la destination Agadir - Je dis du bien sur le lieu même si d'autres ne sont pas d'accord	6	0,955	81,991 81,991	0,894	0,819	**0,964**

Source : Auteur

Discussion des résultats

Les résultats de notre étude ont montré que l'attachement au lieu influence les intentions comportementales. Pour plus de précision et de pertinence, nous nous sommes penchés sur l'effet de chacune des dimensions de l'attachement au lieu sur les intentions comportementales. Ainsi, l'attachement au lieu ou à la destination comporte quatre dimensions : l'identité au lieu, la dépendance au lieu, l'affect au lieu et le lien social, tandis que l'intention comportementale s'est manifestée à travers la revisite et la recommandation.

Notre étude a permis de corroborer l'effet des quatre dimensions de l'attachement sur l'intention de revisiter et de recommander. Ainsi, l'identité au lieu, la dépendance au lieu, l'affect au lieu et le lien social ont montré respectivement un effet sur l'intention de revisiter et de recommander.

Nos résultats s'alignent avec la littérature sur le point qui stipule que l'attachement est un antécédent des intentions comportementales (Ramkissoon, 2015a). En effet, Ramkissoon (2015a) déclare que les dimensions de l'attachement sont des prédicteurs des intentions comportementales. Plusieurs études ont confirmé le rôle important de l'attachement dans la constitution des intentions comportementales, telles que la recommandation d'une destination (Prayag et Ryan, 2012 ; Tsai, 2016 ; Hosany et al., 2017 ; Prayag et al., 2018 ; Liu et al., 2019 ; Zhang et al., 2019).

D'autres études ont abordé l'intention de revisite. Ainsi, elles ont révélé que les attitudes et les intentions de revisiter sont des conséquences de l'attachement au lieu (Kyle et al., 2004 ; Gross et Brown, 2008 ; Rollero et Piccoli, 2010). Conformément aux propos de Ramkissoon (2015a), qui avance que les dimensions de l'attachement sont des prédicteurs des intentions comportementales, Kil et al. (2012) ont signalé le rôle médiateur de l'identité au lieu dans la détermination des intentions de revisite. Quant à la dépendance au lieu, Loureiro (2014) a mentionné son influence positive pour inciter à des intentions de revisite et de recommandation.

Notamment, des études ont approuvé l'intérêt de l'affect au lieu dans la génération des revisites et des recommandations (Hanzaee et Rezaeyeh, 2013 ; de Oliveira et al., 2018). En outre, l'effet du lien social sur les intentions de revisite a été évoqué par un nombre considérable d'auteurs (Neuvonen et al., 2010 ; Rajesh, 2013 ; Lee et al., 2014).

Conclusion

En s'appuyant sur la littérature existante, cette étude confirme que chaque dimension de l'attachement au lieu exerce une influence unique mais complémentaire sur les intentions comportementales. L'identité au lieu, la dépendance au lieu, l'affect au lieu et le lien social se révèlent ainsi être des éléments essentiels pour comprendre et anticiper les comportements de

revisite et de recommandation. Nos résultats enrichissent donc la compréhension des facteurs qui motivent les décisions des visiteurs en matière de revisite et de partage d'expérience, avec des implications importantes pour la gestion et la promotion des destinations touristiques.

Cette étude ouvre la voie à des recherches futures pour explorer plus en profondeur l'interaction entre ces dimensions de l'attachement et d'autres facteurs contextuels, ainsi que leur impact sur la fidélisation des visiteurs. Les résultats suggèrent également des pistes intéressantes pour les praticiens du secteur touristique, qui pourraient exploiter ces dimensions pour renforcer l'engagement des visiteurs et optimiser leurs stratégies de marketing et de développement touristique.

Bien que cette étude fournisse des résultats intéressants et significatifs, elle présente certaines limites qui méritent d'être prises en considération pour de futures recherches.

En effet, les différences culturelles et socio-économiques peuvent influencer l'attachement au lieu et les intentions comportementales, et il serait intéressant de reproduire cette étude dans des contextes variés pour vérifier la transférabilité des conclusions.

L'étude ne prend pas en compte la temporalité de l'attachement au lieu. Les intentions comportementales peuvent évoluer avec le temps, et il est possible que l'attachement au lieu change au fur et à mesure de l'expérience d'un individu. Une étude longitudinale permettrait d'explorer ces variations et d'enrichir la compréhension des relations entre les dimensions de l'attachement et les intentions comportementales à long terme.

Enfin, une autre limite réside dans la possible influence d'autres facteurs externes qui n'ont pas été pris en compte dans cette étude, tels que les événements contextuels (économiques, politiques, sanitaires, etc.) ou les caractéristiques personnelles des individus (âge, niveau d'engagement envers les destinations touristiques, etc.). L'intégration de ces variables pourrait offrir une analyse plus complète des comportements des visiteurs.

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La modélisation numérique dans la démarche d'investigation : Quel impact sur l'acquisition des concepts scientifiques chez les apprenants du primaire?

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Résumé

Dans cette recherche nous cherchons à évaluer l'impact de la modélisation numérique dans la démarche d'investigation sur l'acquisition des concepts scientifiques liées aux sciences de la vie par les élèves du primaire. Dans le cadre d'une démarche de recherche-action réalisée au sein d'un établissement privé de Marrakech, deux groupes d'élèves de 6 ème année primaire, composés de 18 enfants âgés de 10 à 11 ans, ont été impliqués dans l'étude. La collecte des données s'est déroulée en plusieurs phases ; un pré-test sous forme d'une évaluation diagnostique écrite a été administré aux apprenants, après un post-test sous forme d'une évaluation sommative écrite a été effectué pour comparer les progrès réalisés dans chaque groupe et évaluer l'impact de la modélisation numérique sur la compréhension des concepts scientifiques. L'analyse des résultats du pré-test et du post-test met en évidence l'impact de la modélisation numérique sur la compréhension des concepts liés à la reproduction humaine. Au départ, les deux groupes (témoin et expérimental) affichaient des niveaux de connaissances similaires en relation avec la reproduction humaine. Cependant, le post-test met en évidence une amélioration conceptuel notable chez le groupe expérimental.

L'intégration des modèles numériques sous forme de simulations de phénomènes biologiques, tels que la fécondation et le cycle menstruel, pour aider les élèves à visualiser et comprendre ces processus complexes de manière interactive et dynamique semble avoir facilité une organisation plus structurée des connaissances liées à la reproduction chez l'Homme. Les résultats indiquent que les outils d'investigation tels que la modélisation numérique, contribuent à une meilleure compréhension des phénomènes biologiques complexes.

Mots clés : Modélisation numérique, concepts scientifiques, démarche d'investigation, Sciences de la Vie, primaire

Digital modelling in the investigation process: What impact does it have on acquiring scientific concepts for primary school learners?

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Abstract

In this research, we seek to evaluate the impact of digital modelling in the investigative process on primary school learners' acquisition of scientific concepts related to life sciences. As part of an action-research approach carried out in a private school in Marrakech, two groups of 6th-grade primary students, composed of 18 children aged 10 to 11, were covered in the study. Data collection took place over several phases; A pre-test in the form of a written diagnostic assessment was administered to the learners, after a post-test in the form of a written summative assessment was carried out to compare the progress made in each group and to assess the impact of digital modelling on the understanding of scientific concepts. The analysis of the pre-test and post-test results highlights the impact of digital modelling on the understanding of concepts related to human reproduction. Initially, the two groups (control and experimental) had similar levels of knowledge related to human reproduction. However, the post-test showed a noteworthy conceptual improvement for the experimental group. The integration of digital models in the form of simulations of biological phenomena, such as fertilization and the

menstrual cycle, to help students visualize and understand these complex processes in an interactive and dynamic manner seems to have facilitated a more structured organization of knowledge related to human reproduction. The results indicate that investigative tools such as digital modelling contribute to a better understanding of complex biological phenomena.

Keywords: Digital modelling, investigative process, life sciences, primary school, scientific concepts

Introduction

Dans le contexte de l'Afrique francophone, notamment au Maroc, les réformes éducatives concernant l'enseignement des disciplines scientifiques, y compris les Sciences de la Vie et de la Terre, visent à adopter des méthodes pédagogiques fondées sur l'investigation, dans le but de s'éloigner des approches pédagogiques excessivement déductives (Rocard et al., 2007). Des travaux récents ont montré que la modélisation scientifique dès l'école primaire favorise l'intégration des savoirs complexes et le développement de la pensée critique (Arias, Davis & Palincsar, 2023).

Comme à l'échelle éducative internationale, le Maroc a adopté la démarche d'investigation dans l'enseignement des sciences, visant la compréhension des phénomènes naturels, avec une nomenclature évoluant selon les contextes éducatifs et les réformes de chaque pays. Dans le contexte marocain en 2015 dans la vision 2015-2030 au LEVIER 12 : Développement d'un modèle pédagogique ouvert, diversifié, performant et novateur. La démarche d'investigation est implicitement citée comme parmi les méthodes scientifiques et expérimentales que l'apprenant au primaire doit s'en initier, puis la désignation par « la démarche d'investigation » a été introduite dans le Programme révisé de l'éveil scientifique de l'enseignement primaire au Maroc en 2000.

Le programme révisé de l'éveil scientifique de l'enseignement primaire au Maroc propose trois types d'activités méthodologiques à adopter lors de l'enseignement des leçons de l'éveil scientifiques : les activités de construction des concepts, les activités d'application, d'évaluation et du soutien et les activités d'investissement et de prolongation.

C'est dans le cadre des activités de construction des concepts que le programme insère le recours à la démarche d'investigation en sept étapes : la situation initiale, la formulation de la question d'investigation, présentation des hypothèses, précision de la charte du travail, l'investigation et la confrontation aux hypothèses, présentation et échange des résultats et la généralisation.

D'après mon expérience en tant qu'enseignante en SVT, la démarche d'investigation peut intégrer la modélisation numérique, à condition d'adapter

ses objectifs en fonction des différentes étapes de cette démarche. Par exemple, un schéma récapitulatif ou un schéma synthétique peut servir de conclusion (avant-dernière étape de la démarche d'investigation), tout en pouvant aussi être utilisé comme point de départ lors de la phase d'initiation pour poser des questions.

La démarche d'investigation demande l'engagement des apprenants d'une façon autonome sous la direction de l'enseignant. Les modèles, en tant que représentations simplifiées des phénomènes complexes, permettent de mieux les comprendre, de les expliquer ou de les prédire. Ces modèles numériques, comme les simulations informatiques,–représentent ainsi des outils permettant aux apprenants de résoudre un problème scientifique, et de mener leurs investigations. Selon Evagorou et Nielsen (2020), lorsque la modélisation est intégrée dans des démarches d'investigation, elle renforce l'autonomie cognitive, la capacité à raisonner scientifiquement et l'engagement des élèves.

Dans les Sciences de la Vie, la modélisation consiste à établir des liens entre le « monde réel » et le « monde des modèles ». Ces liens peuvent posséder un caractère analogique, c'est-à-dire concevoir un système physique capable de reproduire, de manière approximative, un phénomène que l'on souhaite étudier, ou bien d'ordre mathématique, en élaborant un ensemble de fonctions mathématiques décrivant ce phénomène. Elle favorise également la construction d'explications causales et de prédictions cohérentes, processus clés pour une compréhension scientifique approfondie (Cheng, Lin & Tsai, 2020).

Cependant, quelle que soit sa nature, la modélisation ne constitue pas une activité destinée à reproduire la réalité, mais plutôt à élaborer un modèle capable de décrire et d'expliquer le phénomène en question. Pour permettre aux apprenants de saisir un phénomène particulier, il est nécessaire d'adopter une approche de simplification et de progression. L'enseignant doit en tenir compte en recourant à des modèles pour enseigner des concepts liés aux sciences naturelles, tout en mettant l'accent sur une ou plusieurs de ses caractéristiques essentielles, en fonction des objectifs visés.

Ce travail s'inscrit dans le cadre de l'amélioration des pratiques d'enseignement des Sciences de la Vie au cycle primaire au Maroc, en mettant particulièrement l'accent sur l'utilisation des modèles informatiques pour faciliter la compréhension de phénomènes biologiques tels que la reproduction humaine. La modélisation numérique, dans le cadre de notre recherche, fait référence à l'utilisation de simulations informatiques pour représenter le phénomène de la reproduction humaine de manière visuelle et interactive. Les modèles informatiques utilisés dans cette étude permettent d'illustrer des processus comme le cycle menstruel, la fécondation, et les étapes de la grossesse. Ces simulations offrent aux apprenants une représentation

dynamique et détaillée des phénomènes, ce qui les aide à visualiser et à mieux comprendre les mécanismes sous-jacents. En utilisant ces modèles, les élèves peuvent explorer différentes étapes du phénomène et observer les interactions entre les variables de manière que les méthodes traditionnelles d'enseignement ne permettent pas toujours. Les environnements numériques interactifs, tels que les simulations, améliorent significativement la compréhension des phénomènes biologiques abstraits comme la reproduction humaine (Lee, Pallant & Tinker, 2022).

Cette étude évalue également l'impact de la modélisation numérique sur les apprenants du primaire, en analysant comment cette démarche influe sur leur compréhension de la reproduction chez l'Homme.

Il est à noter que les compétences et les connaissances que le curricula de l'éveil scientifique vise à installer chez les apprenants incitent les enseignants à utiliser des modèles scientifiques dans les différentes phases de la démarche d'investigation (Programme révisé, 2019). Nous, à travers ce travail, visons étudier cette dualité : l'utilisation des modèles scientifiques par les enseignants du primaire et l'adoption de la démarche d'investigation, tout en essayant de répondre à la question de recherche suivante : Quel est l'impact de l'adoption de la modélisation dans l'approche par investigation sur l'acquisition des concepts scientifiques par les apprenants du primaire ? Afin de répondre à cette question, nous avons adopté la méthodologie décrite ci-dessous.

Méthodologie de recherche
Contexte de l'étude

Cette étude s'inscrit dans une démarche de recherche-action menée au sein d'un établissement privé de Marrakech, en impliquant deux groupes de 6éme année primaire (C6a et C6b), comprenant chacun 18 élèves âgés de 10 à 11 ans. La sélection de cet échantillon est motivée par le souhait d'assurer une certaine homogénéité sociale afin de réduire l'impact des facteurs contextuels externes. En collaborant avec deux groupes d'élèves provenant du même établissement, nous avons veillé à ce que les apprenants soient exposés de manière équivalente aux différentes méthodes pédagogiques et aux ressources éducatives disponibles.

Cette démarche de recherche-action, menée en contexte réel d'enseignement, vise à la fois à produire des connaissances sur l'impact de la modélisation numérique dans l'apprentissage scientifique et à améliorer les pratiques pédagogiques en Sciences de la vie au primaire.

Conformément aux principes de la recherche-action, elle a débuté par l'identification d'une problématique de terrain : les difficultés rencontrées par les élèves dans l'appropriation de concepts biologiques complexes tels que la reproduction. En réponse à cela, une séquence pédagogique innovante, fondée

sur l'intégration de simulations et animations interactives, a été conçue et mise en œuvre en étroite collaboration avec les enseignants.

L'expérimentation a été accompagnée d'un dispositif d'observation et de collecte de données (pré-tests, post-tests, observations en classe), permettant d'analyser les effets de l'intervention sur les apprentissages et d'ajuster la séquence pédagogique, dans une dynamique d'amélioration continue.

Méthodologie de collecte des données

La collecte des données s'est déroulée en plusieurs phases afin d'évaluer l'impact des modèles informatiques sur l'apprentissage des phénomènes scientifiques. Cette action s'est étalée sur une période de 1 mois et demi ; depuis le 18 Mars jusqu'à le 09 Mai 2024.

Séances d'observation initiales

Dans un premier temps, des séances d'observation ont été réalisées au sein des deux classes (au total 18 séances) ; Chaque séance d'observation avait une durée moyenne de 45 minutes. Les observations ont été réparties sur une période de 6 semaines, à raison de 2 séances par semaine dans chacune des deux classes. Ces observations avaient un double objectif : d'une part, se familiariser avec l'ambiance générale des classes pour mieux contextualiser l'étude ; d'autre part, collecter des données empiriques permettant d'identifier les pratiques susceptibles d'influencer les conceptions ou les apprentissages des élèves en lien avec la problématique de recherche. Ainsi, ces observations constituent une base essentielle pour comprendre le contexte d'enseignement-apprentissage, repérer d'éventuelles variables explicatives et enrichir l'analyse des résultats obtenus lors des autres phases de la recherche.

Pour la collecte des données, des notes ethnographiques prises pendant et après chaque séance, permettant de recueillir des éléments plus qualitatifs sur l'ambiance, les interactions informelles et les réactions des élèves. Dans certains cas, des enregistrements audios ont été réalisés pour compléter les notes, notamment lors des échanges collectifs.

Pré-test :

Ensuite un pré-test sous forme d'une évaluation diagnostique qui avait une double finalité, d'une part, elle servait à repérer les lacunes persistantes liées aux concepts généraux de la reproduction, en s'appuyant sur les acquis antérieurs des élèves, notamment la reproduction chez les animaux, déjà étudiée, d'autre part, elle permettait d'identifier les représentations initiales spécifiques que les apprenants pouvaient avoir sur la reproduction chez l'Homme, thématique nouvelle à ce stade du programme.

Cette évaluation s'inscrit dans une perspective diagnostique élargie, tenant compte du fait que l'apprenant n'est pas une "feuille blanche", et que toute nouvelle notion est construite à partir de savoirs antérieurs et de conceptions préexistantes.

Le pré-test a donc bien été conçu comme un outil d'exploration préalable, à la fois des acquis et des représentations, dans une logique d'analyse didactique et non simplement de remédiation.

Séquences de cours sur la reproduction chez l'Homme :

Mise en place de deux séquences similaires selon une approche d'investigation scientifique sur le thème « Reproduction chez l'Homme : cycle menstruel, fécondation, grossesse et accouchement ». Une seule variable a été soumise au test :

- o C6a (groupe Témoin) : Adoption de l'analyse documentaire comme outil d'investigation.
- o C6b (groupe expérimental) : Utilisation de la modélisation numérique durant la phase d'investigation active, plus précisément lors de l'étape d'exploration des hypothèses et de visualisation des phénomènes biologiques (comme le cycle menstruel et la fécondation). Concrètement, les élèves du groupe expérimental ont utilisé une simulation numérique interactive via une application en ligne qui permettait de visualiser le déroulement du cycle menstruel, la rencontre des gamètes, le processus de fécondation, puis les différentes étapes de la grossesse jusqu'à l'accouchement.

Ce type de modélisation dynamique visait à favoriser une compréhension systémique et chronologique de phénomènes abstraits difficiles à observer directement. Elle a été utilisée comme support d'analyse, de discussion collective, puis de synthèse.

Nous avons donc précisé dans le texte à quelle étape de la séquence la modélisation est intervenue, quel type d'outil a été utilisé, et quelle était sa fonction pédagogique dans la démarche d'investigation.

Chaque séquence comporte cinq étapes structurées selon la démarche scientifique d'investigation :

- o Recueil des conceptions initiales pour identifier les idées préalables des apprenants concernant le thème étudié.
- o Émergence des questions et hypothèses : discussion interactive pour formuler des hypothèses sur les phénomènes étudiés (cycle menstruel, fécondation, grossesse et accouchement)
- o Vérification des hypothèses : pour la classe C6b nous avons utilisé la simulation numérique et des animations interactives pour visualiser les phénomènes liés à la reproduction humaine, tandis que pour la classe

C6a un recours à l'analyse documentaire a été choisi comme outil d'investigation.
- o Institutionnalisation et conclusion : synthèse des résultats et validation collective des connaissances.
- o Mise en application : Activités pratiques pour appliquer les concepts appris.

Dans cette étude, la modélisation numérique sous forme de simulations et d'animations interactives a été utilisée comme outil d'investigation, permettant aux élèves de vérifier les hypothèses qu'ils ont formulées au début de la séquence en relation avec la reproduction humaine. Ce choix s'inscrit dans le cadre de la démarche d'investigation adoptée dans les manuels d'éveil scientifique du primaire marocain, qui visent à développer chez les apprenants dès le cycle primaire des compétences de questionnement, d'émission d'hypothèses et de recherche scientifique.

Ces outils numériques interactifs ont permis aux élèves de visualiser des phénomènes biologiques abstraits, tels que la fécondation et le cycle menstruel, et de confronter leurs représentations initiales à des modèles scientifiques dynamiques, renforçant ainsi leur compréhension et leur autonomie dans la construction du savoir.

Post-test

Enfin un post-test sous forme d'une évaluation sommative écrite a été effectué pour comparer les progrès réalisés dans chaque groupe et évaluer l'impact de la modélisation numérique sur la compréhension des concepts scientifiques.

Analyse des Données
- o Données quantitatives analysées avec IBM SPSS Statistics 20 et Microsoft Excel 365.
- o Analyse comparative des résultats entre les deux groupes (expérimental et témoin).
- o Calcul des moyennes, écarts-types et tests statistiques (ex. : test du Khi²) pour évaluer l'impact de la modélisation numérique sur sur l'acquisition des connaissances en relation avec la reproduction humaine.

Résultats
Analyse du pré-test :
**Question 1 :** Quel événement marque le début du cycle menstruel chez les filles ?
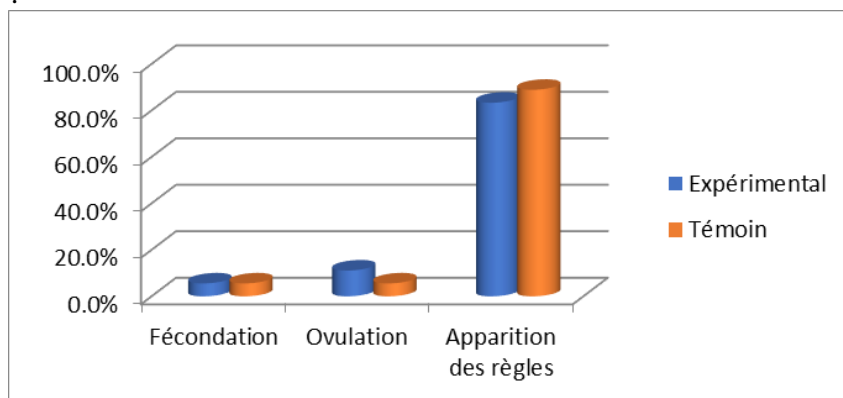
Figure 1 : Répartition des réponses des apprenants concernant l'événement qui marque le début du cycle menstruel chez la femme

Dans cette question, nous avons demandé aux apprenants de déterminer l'événement qui marque le début du cycle féminin. Les résultats obtenus montrent que la majorité des élèves (86,1%) des deux groupes (témoin et expérimental) a opté pour la réponse « Apparition des règles », qui est la bonne réponse (Fig.1). Par contre 13,9% des élèves enquêtés ont choisi respectivement l'ovulation (8,3%) et la fécondation (5,6%) comme étant les premières phases du cycle féminin (Fig.1).

D'après les résultats obtenus, il nous semble que les apprenants interrogés ont des connaissances correctes au sujet de l'événement qui intervient dans le déroulement du cycle féminin (apparition des règles) ainsi que son emplacement dans ce cycle.

Question 2 : Où se produit la fécondation ?
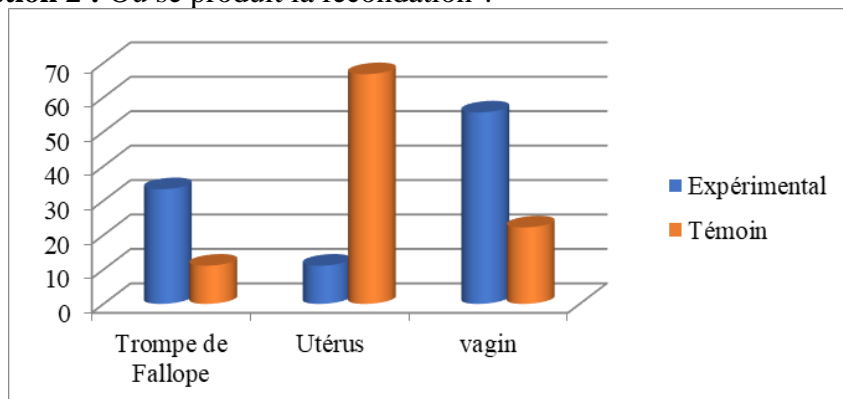
Figure 2 : Répartition des réponses des apprenants concernant le lieu de la fécondation chez la femme

À travers cette question, nous avons sollicité les apprenants de déterminer le lieu de déroulement de la fécondation chez la femme, à savoir que « Trompes de Fallope » est la bonne réponse à cocher (Fig.2). D'après les résultats obtenus, nous avons remarqué que les 22,2% des élèves enquêtés des deux groupes ont opté pour les Trompes de Fallope comme étant le lieu de déroulement de la fécondation. Pourtant « Utérus » a été la réponse choisie par les apprenants du groupe témoin (66,7%) et « Vagin » est choisi par les apprenants du groupe expérimental (55,6%) (Fig.2). Ces données montrent la présence des conceptions erronées chez l'ensemble des apprenants interrogés concernant le lieu de déroulement de la fécondation.

Question 3 : Où s'effectue le développement de la cellule-œuf après la fécondation ?
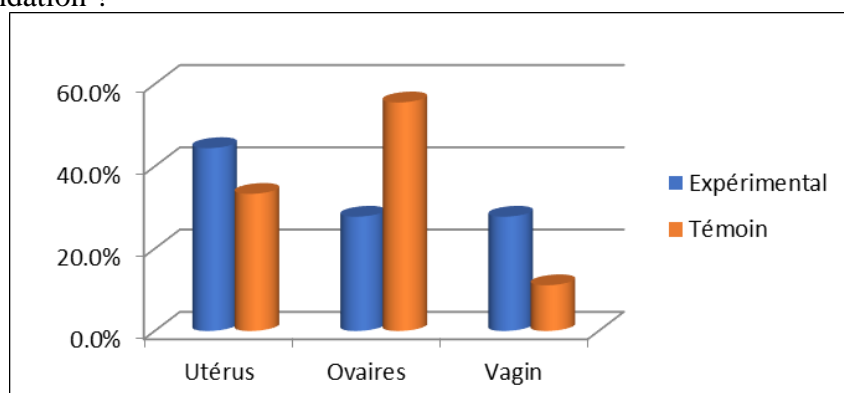
Figure 3 : Répartition des réponses des apprenants concernant le lieu du développement de la cellule-œuf après la fécondation

Dans cette question, nous avons demandé aux apprenants de déterminer le lieu de développement de la cellule-œuf après la fécondation (Fig.3). La plupart des apprenants du groupe témoin (55,6%) a choisi les « ovaires », tandis que 44,4% des apprenants du groupe expérimental ont choisi la bonne réponse qui est « l'utérus » et le « vagin » est choisi par 19,4% des apprenants des deux groupes (Fig.3). D'après les résultats obtenus, nous pouvons dire que les apprenants mélangent entre le lieu du déroulement de l'ovulation et celui de la fécondation.

Note du pré-test

Lors de la correction des feuilles du pré-test des deux groupes nous avons adopté une échelle pour noter les réponses des apprenants.
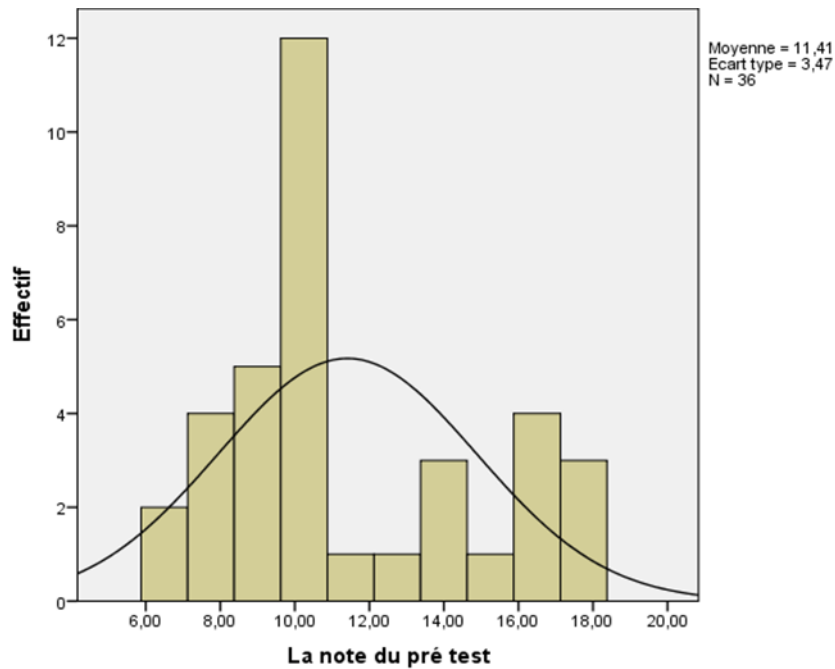
Figure 4 : Pré-test : répartition des résultats (moyenne et écart-type)
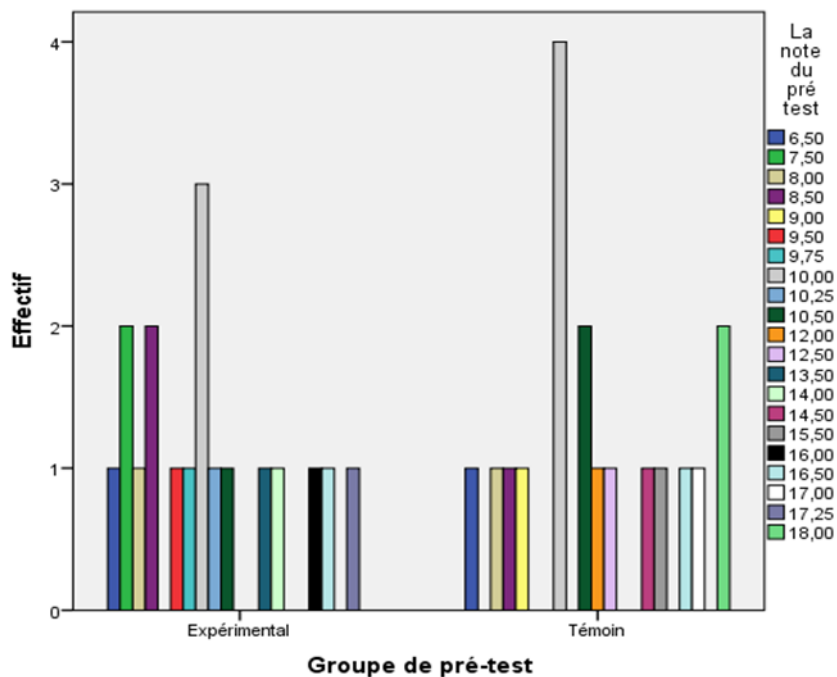
Figure 5 : Répartition des notes obtenues par le groupe témoin et le groupe expérimental au pré-test

La moyenne du pré-test réalisé est 11.41 ; en plus la plupart des apprenants ont eu des notes qui varient entre 10 et 10,5. En comparant les moyennes des deux groupes à l'aide du test t, on trouve qu'il n'y a pas une différence significative entre le groupe témoin et le groupe expérimental ; ceci veut dire que la majorité des apprenants ont un bagage conceptuel restreint à propos de la reproduction chez l'Homme.

Analyse du post-test

Le post-test est destiné aux mêmes apprenants qui ont répondu au pré-test. Il s'agit d'une évaluation sommative (voir annexe) qui touchent l'ensemble des connaissances et compétences acquises lors de séances assurées en relation avec la reproduction chez l'Homme, pour le groupe témoin et le groupe expérimental.

Exercice 1

Dans cet exercice nous demandons aux apprenants de relier chaque terme proposé avec sa définition.
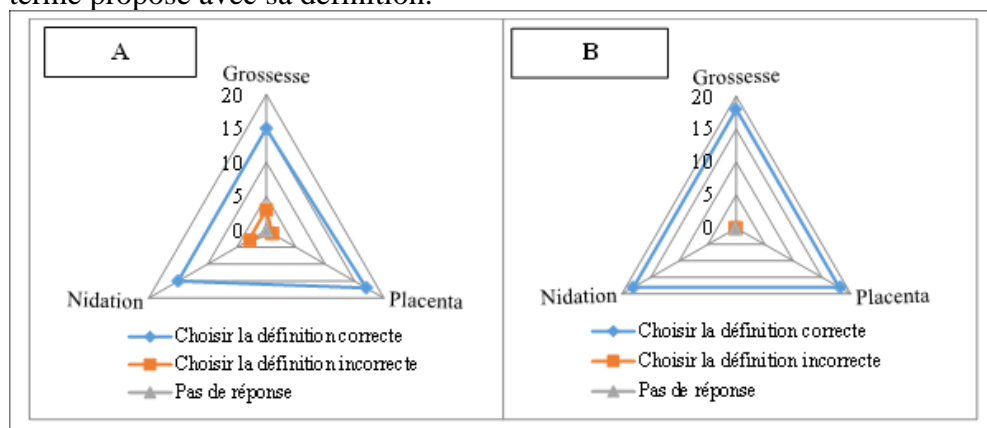

Figure 6 : Association des termes avec leurs définitions appropriées
(A : Groupe témoin / B : Groupe expérimental)

Tous les apprenants du groupe expérimental ont correctement associé les termes proposés à leurs définitions, tandis que certains apprenants du groupe témoin n'ont pas réussi à relier les termes « grossesse » et « nidation » à leurs définitions appropriées.

Exercice 2

Dans cet exercice nous demandons aux apprenants de chasser le terme intrus dans 4 listes (voir annexe), afin de savoir si les apprenants peuvent différencier entre les termes utilisés dans les champs contextuels abordés dans le cours.
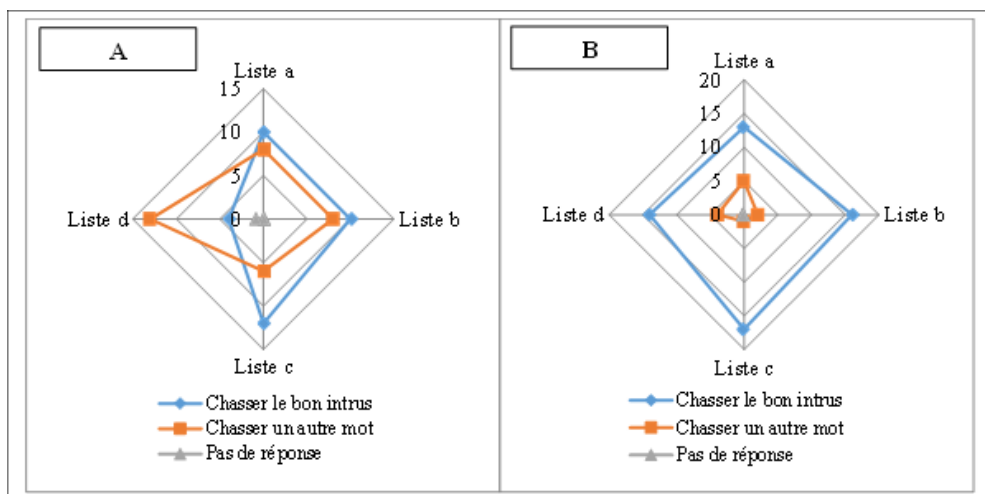
Figure 7 : Identification de l'élément intrus (A : Groupe témoin/ B : Groupe expérimental)

La majorité des apprenants du groupe expérimental a correctement identifié l'intrus dans chacune des quatre listes (Fig.7) :

- o   Liste a : 17 sur 20, soit 85 % de réussite
- o   Liste b : 16 sur 20, soit 80 %
- o   Liste c : 18 sur 20, soit 90 %
- o   Liste d : 17 sur 20, soit 85 %.

Ces résultats montrent une très bonne assimilation des distinctions terminologiques abordées dans le cours de la reproduction humaine, confirmant que l'intervention pédagogique appliquée (adoption de la simulation et des animations interactives) à ce groupe a eu un effet positif sur leur capacité d'analyse lexicale.

Dans le groupe témoin, les résultats sont plus contrastés :

Listes a et b : 10 apprenants sur 20 ont identifié correctement l'intrus, soit 50 % de réussite, tandis que 8 ont choisi un autre mot et 2 n'ont pas répondu ;

Liste c : 12 apprenants ont bien répondu (soit 60 %) ;

Liste d : seulement 6 apprenants ont identifié le bon intrus (30 %), tandis que 13 ont sélectionné un autre mot.

Ces résultats suggèrent que les apprenants du groupe témoin rencontrent des difficultés à distinguer les termes liés au champ contextuel traité dans le cours de la reproduction chez l'Homme.

Exercice 3

Dans cet exercice nous demandons aux apprenants de légender à l'aide des termes donnés le document proposé qui montre le schéma de l'appareil génital de la femme en phase de grossesse :
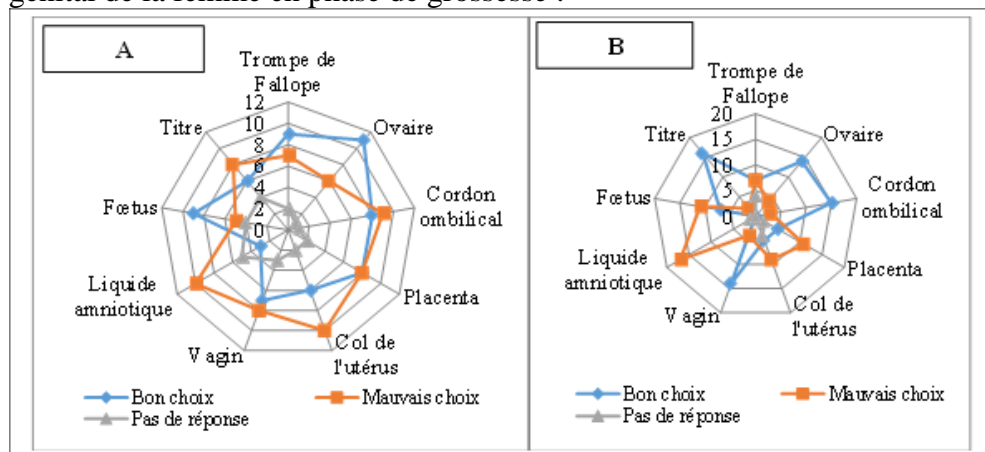

Figure 8 : Sélection des termes correspondant au schéma proposé
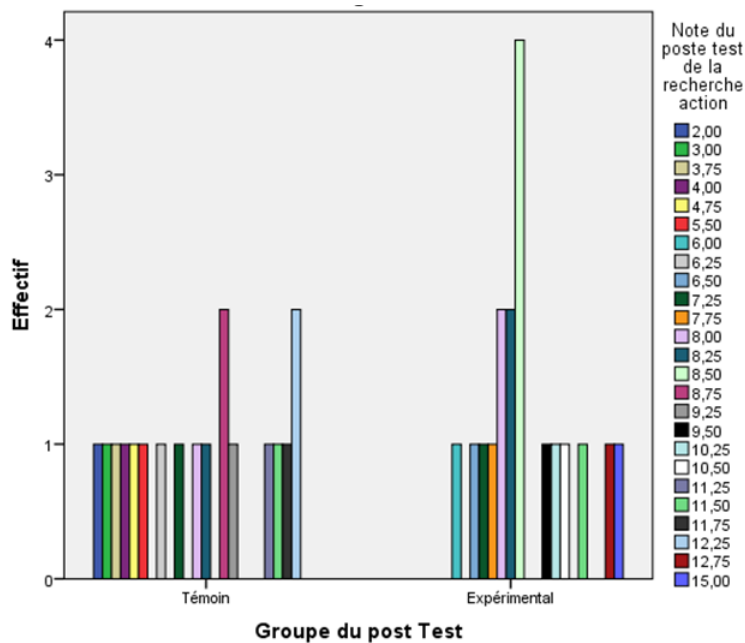(A : Groupe témoin / B : Groupe expérimental)

Les apprenants des deux groupes ont rencontré des difficultés à lire correctement le schéma proposé.

La majorité des apprenants du groupe expérimental n'a pas pu identifier certains éléments, en particulier le placenta, le liquide amniotique et le col de l'utérus. En revanche, les résultats du groupe témoin montrent une difficulté encore plus marquée, car la plupart des apprenants n'ont pas su reconnaître la majorité des éléments du schéma, à l'exception de l'ovaire, de la trompe de Fallope et du fœtus. L'analyse par le test du Chi-deux d'indépendance confirme l'existence de divergences significatives dans les réponses des apprenants des deux groupes.

Note du post test :

Moyenne = 8,39
Ecart type = 2,884
N = 36
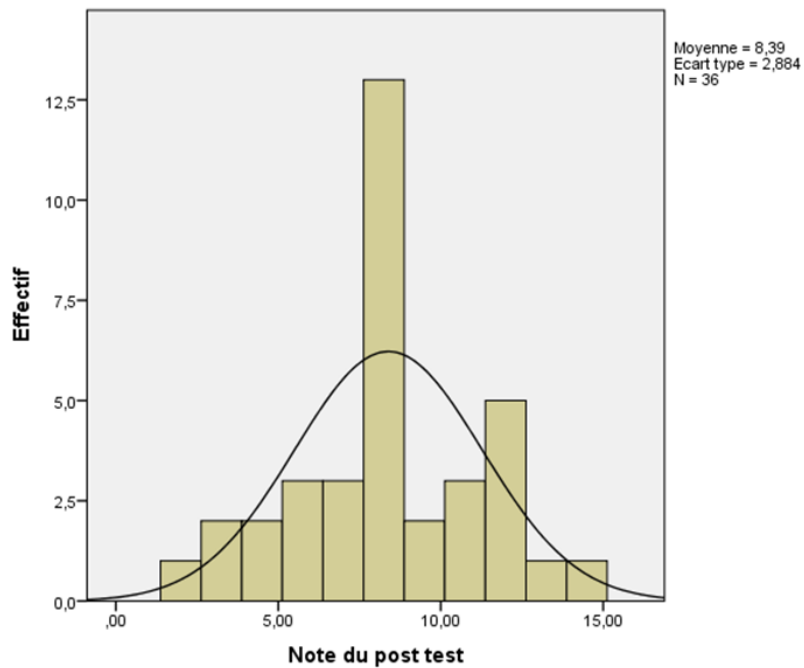
Figure 9 : Post-test : répartition des résultats (moyenne et écart-type)

Figure 10 : Répartition des notes obtenues par le groupe témoin et le groupe expérimental au post-test

La moyenne du post-test réalisé est 8,39. En tenant compte du fait que les apprenants du groupe expérimental ont pu répondre correctement à la majorité des questions du post test par rapport aux apprenants du groupe témoin, on peut dire que les apprenants du groupe expérimental ont pu développer des connaissances et des compétences plus stables et correctes par rapport aux apprenants du groupe témoin à propos de la reproduction chez l'Homme. Ce résultat est en cohérence avec les travaux de Arias, Davis et Palincsar (2023), qui montrent que les modèles interactifs aident à reconstruire les représentations initiales erronées chez les élèves.

Discussion

Cette analyse compare les résultats des pré-tests et post-tests réalisés auprès des groupes témoin et expérimental afin d'évaluer les connaissances sur la reproduction chez l'Homme. Les résultats révèlent une amélioration significative des performances du groupe expérimental après l'intervention pédagogique. Cette progression s'explique notamment par l'utilisation de la modélisation scientifique comme outil d'investigation, qui permet aux élèves de représenter, manipuler et discuter des concepts complexes de manière dynamique. De Jong, Sotiriou et Gillet (2021) soulignent que les simulations numériques permettent aux élèves de manipuler virtuellement des variables, renforçant ainsi leur compréhension des systèmes dynamiques en biologie. Des études ont montré que cette approche favorise la conceptualisation et renforce les apprentissages en sciences (Justi & Gilbert, 2002 ; Louca & Zacharia, 2012). Par exemple, Justi et Gilbert (2002) ont souligné que la construction et l'évaluation de modèles permettent aux élèves de mieux comprendre les phénomènes scientifiques en leur donnant une structure explicative. De même, Louca et Zacharia (2012) ont démontré que les activités de modélisation développent non seulement les connaissances scientifiques mais aussi les compétences de raisonnement et de réflexion critique. Ces résultats sont également en accord avec l'approche du Modeling Instruction développée par Hestenes (1992), qui a montré une amélioration significative de la compréhension conceptuelle chez les élèves lorsqu'ils participent activement à l'élaboration et à la révision de modèles scientifiques.

Concernant le pré-test, les deux groupes présentaient des niveaux de connaissances comparables (moyenne de 11,41), sans différence significative. Cela confirme l'homogénéité initiale des groupes, une condition essentielle pour évaluer l'impact des interventions pédagogiques ultérieures (Cohen et al., 2018).

86,1 % des apprenants identifiaient correctement les règles comme marquant le début du cycle menstruel, en accord avec l'étude sur les représentations sociales des cycles féminins (Rembeck & Möller, 2006).

La faible proportion d'apprenants (22,2 %) ayant correctement localisé la fécondation dans les trompes de Fallope, alors que d'autres optaient pour l'utérus ou le vagin, montre une méconnaissance des processus physiologiques impliqués. Cette confusion reflète, comme le souligne Tunnicliffe (2001), une représentation simplifiée et parfois erronée des événements reproductifs chez l'Homme.

Plusieurs facteurs peuvent expliquer ces constats préliminaires ; bien que certaines études suggèrent que le sexe peut influencer la compréhension de certains concepts biologiques (par exemple, une meilleure connaissance des organes masculins chez les garçons ou une plus grande sensibilité aux questions liées au cycle chez les filles), le test Chi-deux d'indépendance n'a pas permis d'établir de corrélation significative entre le sexe et les erreurs observées. Cette absence de lien confirme que les difficultés identifiées relèvent plus de la complexité des concepts que d'un biais sexuel (Andersen & Ward, 2014).

Dans le post-test, les résultats montrent une amélioration notable des performances du groupe expérimental, notamment dans l'exercice 2, qui consistait à relier des termes scientifiques à leurs définitions. Ce groupe a obtenu un taux de réussite de 100 %, tandis que le groupe témoin a commis plusieurs erreurs dans le même exercice. Cette différence de performance suggère que l'intégration de la modélisation numérique dans une démarche d'investigation a eu un effet positif sur l'assimilation des concepts clés liés au thème étudié. L'usage de cette approche semble avoir favorisé une meilleure structuration des connaissances et une compréhension plus fine des notions abordées.

Ce résultat suggère que l'intégration de la modélisation numérique a contribué à une meilleure compréhension immédiate du vocabulaire spécialisé mobilisé dans l'activité. Toutefois, en l'absence d'un post-test différé, il n'est pas possible de conclure sur une éventuelle consolidation ou mémorisation durable de ces acquis, corroborant les travaux de Hmelo-Silver (2004). La capacité du groupe expérimental de distinguer correctement entre les termes liés à des champs contextuels différents (par exemple, différencier « placenta » de « spermatozoïde ») indique une intégration distinctive des connaissances, conformément aux principes de l'apprentissage significatif (Ausubel, 1963).

Dans l'exercice 1, Les résultats du groupe expérimental indiquent une bonne compréhension des concepts clés, probablement grâce à l'approche pédagogique innovante utilisée (simulations/animations interactives). Le groupe témoin montre des lacunes, en particulier sur des notions souvent confondues ou abstraites comme « nidation », ce qui suggère que l'enseignement classique est moins efficace pour ancrer ces concepts.

Certaines erreurs de légendage observées chez le groupe expérimental (exercice 3), notamment concernant le placenta et le liquide amniotique,

peuvent être dues à la complexité de ces concepts, qui nécessitent une compréhension précise de leur fonction et de leur position dans le corps humain. Bien que l'interaction avec la modélisation numérique ait amélioré la compréhension de nombreux éléments clés, il est possible que certains aspects, plus abstraits, n'aient pas été aussi facilement identifiables lors de l'exercice. Ces erreurs peuvent également être liées à la nature spécifique des termes scientifiques, qui demandent parfois une révision ou un approfondissement supplémentaire pour assurer une parfaite assimilation. Les apprenants du groupe témoin ont eu encore plus de difficultés, car ils n'ont pu identifier correctement l'ovaire, la trompe de Fallope et le fœtus, suggérant une reconnaissance limitée des structures du schéma.

Le contraste entre les résultats du groupe témoin et expérimental met en évidence que ce dernier a réussi à surmonter certaines confusions initiales, notamment en ce qui concerne la fonction des gamètes et l'assignation correcte des rôles des organes reproducteurs. Ces progrès soutiennent l'hypothèse selon laquelle des interventions pédagogiques bien ciblées peuvent améliorer l'apprentissage des concepts complexes en sciences (Hattie, 2009).

La moyenne du pré-test était de 11,41, avec des résultats homogènes entre le groupe témoin et le groupe expérimental. Toutefois, après l'intervention, la moyenne du post-test a chuté à 8,39. Ce résultat peut être interprété de plusieurs manières :

o Bien que le post-test ait mobilisé des compétences plus complexes que le pré-test ; en demandant notamment une capacité d'analyse et de discrimination lexicale fine, les résultats du groupe expérimental montrent qu'ils ont su transférer les savoirs acquis grâce à l'intervention pédagogique, ce qui témoigne d'un réel apprentissage en profondeur.

o Une transition entre connaissances erronées et construction de nouveaux savoirs : Comme l'expliquent les modèles constructivistes de l'apprentissage, la révision de conceptions initiales erronées peut temporairement déstabiliser les apprenants.

o L'analyse des résultats met en évidence un impact différencié selon les groupes. Le groupe expérimental a montré une meilleure assimilation des concepts abordés, notamment en ce qui concerne la précision lexicale et la compréhension des processus biologiques comme la nidation ou la grossesse. Cette différence significative peut être attribuée à la stratégie pédagogique mise en œuvre : l'intégration de simulations numériques et d'animations interactives. En mobilisant une approche visuelle et dynamique, ces outils ont favorisé une meilleure conceptualisation des phénomènes complexes de la reproduction humaine, tout en renforçant l'engagement des apprenants. Ces résultats suggèrent que cette stratégie favorise non

seulement l'acquisition de connaissances, mais aussi leur mobilisation dans des tâches cognitives plus élaborées, telles que la discrimination terminologique et la mise en relation de concepts.

La comparaison des moyennes entre les groupes, appuyée par le test Chi-deux d'indépendance, révèle que le groupe expérimental a globalement mieux intégré certains concepts. Ces approches permettent aux apprenants de passer d'une connaissance superficielle à une compréhension plus approfondie, en favorisant la réflexion et la réorganisation des représentations mentales.

Conclusion

Les résultats de cette étude mettent en évidence l'impact significatif des interventions pédagogiques structurées, notamment celles intégrant la modélisation numérique dans une démarche d'investigation, sur l'amélioration des connaissances des apprenants concernant le système reproducteur humain. L'approche utilisée repose sur l'utilisation de simulations interactives et de modèles numériques dynamiques, permettant aux élèves d'explorer activement les concepts scientifiques, de formuler et tester des hypothèses, et de visualiser des processus biologiques habituellement abstraits tels que la fécondation ou la nidation.

Cette stratégie pédagogique s'inscrit dans le champ des méthodes actives d'apprentissage, dont l'efficacité a été largement démontrée dans l'enseignement des sciences. Les résultats obtenus dans cette recherche confirment les conclusions d'études antérieures telles que celles de Prince (2004) ou encore Hmelo-Silver et al. (2007), qui soulignent que les approches centrées sur l'investigation favorisent non seulement l'engagement cognitif des élèves, mais aussi une compréhension conceptuelle plus approfondie. De même, selon Roediger & Karpicke (2006), la combinaison d'une pédagogie active et de la répétition espacée améliore à la fois la compréhension et la rétention des connaissances.

Dans le cadre de cette recherche, les élèves ayant été exposés régulièrement à des tâches impliquant la modélisation numérique et l'investigation scientifique ont développé une compréhension plus solide des mécanismes biologiques liés à la reproduction humaine. Cheng, Lin et Tsai (2020) affirment que l'intégration de la modélisation dans l'enseignement des sciences engage les élèves dans un processus actif de construction des connaissances basé sur l'explication, la prédiction et la validation scientifique. Ce constat découle directement des résultats obtenus et ne se limite pas aux conclusions des travaux antérieurs. Il met en lumière l'intérêt de concevoir des séquences pédagogiques où les élèves ne se contentent pas de recevoir l'information, mais participent activement à la construction du savoir.

Au-delà de l'aspect purement théorique, cette étude ouvre la voie à des améliorations concrètes des pratiques d'enseignement en SVT. L'intégration raisonnée des outils numériques ne doit pas être perçue comme un simple enrichissement technologique, mais bien comme un levier de transformation pédagogique. En permettant de simuler des phénomènes invisibles ou complexes, les modèles numériques facilitent l'appropriation des savoirs et contribuent au développement des compétences scientifiques, techniques, mais aussi critiques et analytiques.

Il devient dès lors essentiel de concevoir des activités d'enseignement qui articulent modélisation, expérimentation et réflexion métacognitive, afin de proposer aux apprenants des situations d'apprentissage riches et motivantes. L'étude montre également l'importance de varier les stratégies pédagogiques, notamment pour les notions difficiles liées à la reproduction humaine. L'adoption d'approches multisensorielles, alliant collaboration, supports visuels et stratégies de régulation cognitive, apparaît comme une voie prometteuse pour répondre à la diversité des profils d'apprentissage.

Malgré les résultats encourageants obtenus, cette étude présente certaines limites qu'il convient de reconnaître :

- **Échantillon restreint et contextuel** : L'étude a été menée auprès d'un nombre limité d'élèves appartenant à un contexte scolaire spécifique (type d'établissement, niveau scolaire, environnement numérique). Les résultats, bien que significatifs, ne peuvent donc pas être généralisés à l'ensemble du système éducatif sans précautions.
- **Durée de l'intervention** : L'expérimentation pédagogique s'est déroulée sur une période relativement courte. Il est possible que les effets positifs observés soient liés à un effet de nouveauté ou à un engagement ponctuel. Une observation à long terme serait nécessaire pour évaluer la stabilité des acquis et leur transfert dans d'autres contextes.
- **Évaluation centrée sur les connaissances** : L'évaluation a principalement porté sur les acquis cognitifs (compréhension, restitution, discrimination lexicale). D'autres dimensions de l'apprentissage (motivation, autonomie, collaboration) n'ont pas été systématiquement mesurées, alors qu'elles peuvent également être influencées par l'usage des outils numériques.
- **Inégalités d'accès au numérique** : Tous les élèves n'ont pas nécessairement le même degré de familiarité avec les outils numériques. Cette hétérogénéité peut influencer leur capacité à tirer pleinement parti des dispositifs proposés.

À partir de ces constats, plusieurs pistes d'approfondissement peuvent être envisagées :

- **Élargissement de l'échantillon** : Il serait pertinent de reproduire cette étude auprès de populations scolaires plus variées (zones rurales/urbaines, différents niveaux scolaires, contextes multilingues) pour vérifier la transférabilité des résultats.
- **Études longitudinales** : Une démarche sur le moyen ou long terme permettrait d'évaluer l'impact durable des modèles numériques sur la compréhension scientifique, ainsi que sur la rétention et le transfert des connaissances.
- **Intégration d'indicateurs socio-affectifs** : De futures recherches pourraient intégrer des dimensions telles que la motivation, l'attitude face aux sciences, ou encore le développement de la pensée critique, afin de mieux cerner les effets globaux de l'approche.
- **Conception de séquences pédagogiques hybrides** : L'intégration de la modélisation numérique dans des séquences combinant également des expériences réelles, des jeux de rôle ou des débats argumentatifs permettrait de diversifier les modalités d'apprentissage et de favoriser un enseignement plus inclusif.
- **Formation des enseignants** : Une réflexion autour de la formation initiale et continue des enseignants à l'utilisation pédagogique des outils numériques est essentielle pour garantir une implémentation efficace et cohérente de ces dispositifs dans les pratiques de classe.

Déclaration pour les participants humains : L'étude de recherche-action a été approuvée par un comité d'Experts en Didactique des Sciences à l'École Normale Supérieure (ENS), Université Cadi Ayyad de Marrakech. Les participants, apprenants du primaire, ont été informés de l'objectif de l'étude, et leur consentement éclairé a été obtenu. L'anonymat des participants a été rigoureusement préservé, et toutes les informations ont été traitées avec la plus grande confidentialité.

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Annexe : Evaluation sommative (10/10)

Exercice 1 : Relier par une flèche chaque terme avec la définition convenable : **(3 points)**

Groupe A
Grossesse
Placenta
Nidation
Groupe B
- Implantation de l'embryon dans la paroi utérine.
- Organe qui permet au futur bébé de puiser dans le sang maternel l'eau, les nutriments et l'oxygène nécessaire à son développement.
- Ensembles des phénoménes durant lesquels l'embryon , puis le fœtus , se développe dans l'utérus maternel.

Exercice 2 : Chasser l'intrus dans chacune des listes suivantes : **(4 points)**
**a :** Spermatozoïde – ovule – placenta – trompe de Fallope.
b : Phase embryonnaire – adolescence – grossesse – phase fœtale.
c : L'hygiène – la chaleur – la respiration – fécondation – l'allaitement maternel
d : Dilatation – ovulation – expulsion – délivrance.

Exercice 3 : Légender le document ci-dessous en utilisant les termes suivants : col de l'utérus, trompe de Fallope, vagin, cordon ombilical, ovaire, placenta, fœtus, liquide amniotique **(3 points)**

1 : ....
2 : ....
3 : ....
4 : ....
5 : ....
6 : ....
7 : ....
8 : ....
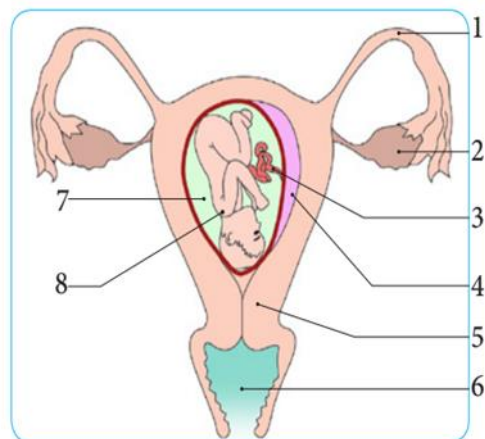
Resilience Strategies in Moroccan Artisanal Supply Chain Networks

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Abstract

This study examines the resilience strategies employed by Moroccan artisans within cooperative and traditional business supply chain networks, analyzing how these networks navigate disruptions while ensuring livelihoods and preserving cultural heritage. Adopting an inductive approach, the research utilizes the Gioia methodology to analyze qualitative data from semi-structured interviews, applying a structured coding process through Qualcoder to identify key resilience mechanisms, progressing from first-order codes to second-order themes and aggregate dimensions. The findings reveal that while both cooperative and traditional business supply chain networks share similarities in resilience mechanisms, their network structures fundamentally shape how these mechanisms operate, particularly through differences in governance, decision-making, and resource coordination. However, in both types of networks, resilience emerges as an ongoing, adaptive process shaped by crises, internal tensions, and strategic responses. Despite the study's contributions, its small sample size and cross-sectional design limit generalizability and the ability to capture long-term resilience dynamics. Nevertheless, the findings provide valuable insights for policymakers and organizations supporting artisans to design targeted resilience-enhancing interventions. By shifting the focus

from corporate supply chains to small-scale, informal artisanal networks, this study contributes to the literature on supply chain resilience, highlighting the unique adaptive capacities embedded in traditional craftsmanship.

Keywords: Gioia Methodology, Moroccan Artisanal Networks, Supply Chain Networks, Supply Chain Resilience

Introduction

In Morocco's lively medinas, two key economic models shape the craft industry: individual artisans and artisanal cooperatives. Both play vital roles in preserving traditional skills while adapting to modern challenges. Individual artisans focus on mastering their craft, often relying on techniques handed down through generations (Rondi et al., 2024). In contrast, cooperatives emphasize teamwork, pooling resources and knowledge to create collective products. (Ghobadi & D'Ambra, 2012) Understanding the resilience of these networks is essential to learning how small artisans overcome challenges, maintain their livelihoods, and protect their cultural heritage in a changing world. While extensive research has focused on large-scale corporate networks, studies on informal, artisanal networks, which are critical for cultural preservation and economic sustainability, remain limited (Birchall, 2011; Wieland & Wallenburg, 2013).

This study fills this gap by investigating Moroccan artisanal networks, highlighting how both cooperative and traditional business models adapt to crises. By employing the Gioia methodology (Gioia et al., 2013), the research develops a grounded framework for resilience that integrates cultural, social, and economic dynamics specific to artisanal supply chains. For Moroccan artisans, renowned globally for their rich cultural heritage and craftsmanship (Shafer, 2019), resilience is not an abstract theoretical construct, it is a daily necessity. These artisans are facing fluctuating markets, limited access to resources, and intensifying competition from industrialized producers. Despite their vital contributions to Morocco's cultural and economic fabric, the mechanisms by which they build and sustain resilience remain poorly explored.

Existing research on supply chain resilience has predominantly concentrated on large-scale corporate networks, which often benefit from formalized systems, advanced technologies, and institutional support (Christopher & Peck, 2004; Wieland & Wallenburg, 2013). While these studies provide valuable insights into resilience frameworks, they tend to overlook the unique dynamics of small-scale and informal networks, especially in developing economies (Pettit et al., 2010).

The originality of our study lies in addressing this gap with an inductive approach to explore how Moroccan artisans build resilience within two distinct network structures: cooperative networks and traditional business networks.

Using the Gioia methodology (Gioia et al., 2013), this study seeks to uncover the nuanced strategies and interactions that underpin resilience within these networks. By iteratively analyzing qualitative data, we identify the mechanisms through which artisans navigate unexpected disruptions. The findings of this study reveal that cooperative networks foster resilience through shared governance, collective bargaining, and resource pooling, while traditional networks leverage entrepreneurial ingenuity, relational trust, and individualized supply chain management. These contrasting pathways highlight the interplay between structural context and strategic adaptation, offering critical insights into how small-scale, informal networks respond to adversity.

This research contributes to the growing body of literature on supply chain resilience by shifting the focus from formal corporate structures to the often-overlooked informal networks that characterize small-scale enterprises. By integrating contextual factors, network dynamics, and resilience strategies, this study provides a grounded framework for understanding resilience in artisanal supply chains.

Theoretical Background

This study adopts an inductive approach grounded in empirical data, guided by the Gioia methodology (D. Gioia, 2021), to develop a theoretical framework rooted in the lived experiences and perspectives of Moroccan artisans. This approach enables a nuanced understanding of resilience within artisanal supply chains by allowing constructs to emerge directly from the data, thereby providing a grounded theory that reflects the complexities of local practices and contexts (Charmaz, 2014; Suddaby, 2006).

Resilience in Artisanal Supply Chains

Resilience has increasingly been conceptualized not as a static trait, but as a dynamic, emergent process (Ponomarov & Holcomb, 2009). In the context of artisanal supply chains, resilience is more than the ability to recover from disruptions; it reflects the ongoing process of adapting to changes, absorbing shocks, and continuously evolving in response to challenges (Christopher & Peck, 2004). Artisanal networks - characterized by a combination of traditional knowledge and modern economic pressures - require resilience strategies that balance innovation, resourcefulness, and social cooperation (Bhamra et al., 2011; Ming et al., 2021). These networks must absorb disruptions, reconfigure their resources, and transform

themselves in response to market, social, and environmental pressures (Miller et al., 2014; Brundin, 2016; Seville et al., 2008).

Recent research highlights the importance of adopting a multidimensional approach to resilience, particularly in contexts where formal institutions are weak or non-existent. Such approaches integrate various dimensions, including network structure, social capital, and adaptive capacity, which together provide a comprehensive understanding of resilience (Sheffi & Rice, 2005; Vogus & Sutcliffe, 2007; Walker et al., 2004).

Social Capital and Trust

Social capital has been extensively identified as a critical determinant of resilience in supply chains (Teece et al., 1997a). The ability of artisans to navigate crises is heavily influenced by the strength and diversity of their social networks (Jüttner & Maklan, 2011; Nahapiet & Ghoshal, 2009a). In artisanal contexts, social capital manifests through both bonding and bridging social capital (Saad & Youness, 2024).

Bonding social capital, typified by strong, trust-based relationships among closely-knit members, enables rapid mobilization of internal resources during crises and facilitates internal problem-solving. Conversely, bridging social capital - representing connections with external networks and resources - enables access to diverse knowledge, innovation, and adaptive strategies, essential for managing complex challenges and sustaining long-term viability. The interplay between these forms of social capital is a central mechanism of resilience, as it supports both immediate crisis management and long-term adaptation to external shocks (Möller & Rajala, 2007; Scholten & Schilder, 2015).

Continuous Learning

Continuous learning in artisanal supply chains relies on informal, experiential knowledge. (Bhamra et al., 2011) highlight "learning by doing," where knowledge is passed down through practice rather than formal training. Lengnick-Hall & Beck (2009)stress that this adaptive learning is key to resilience, allowing artisans to quickly respond to challenges.

Eslami et al. (2020) note that artisanal networks thrive through shared knowledge, facilitated by social interactions. Fisher (2010) introduces "adaptive bricolage," where artisans creatively adapt resources, fostering continuous learning without formal systems. Simmie & Martin (2010) further emphasize the role of relational dynamics in this process.

In sum, continuous learning in artisanal supply chains is driven by tacit knowledge and collaborative adaptation, ensuring resilience in times of disruption.

Research Gaps

This study fills several significant research gaps by shifting attention from corporate supply chains to small-scale, informal artisanal networks. It offers a comparative analysis of cooperative and traditional networks, demonstrating how variations in structure and organization lead to unique ways of operationalizing resilience. Additionally, it highlights the often-overlooked human factor and interpersonal synergy as key elements in sustaining resilience within these networks. Finally, by applying the Gioia methodology to qualitative data, this study provides deeper insights into the preservation of livelihoods and cultural heritage, particularly in the face of disruptions.

Methodology

The study employs the Gioia methodology (Gioia et al., 2013) to address the core research question: "*How do Moroccan artisans define resilience within their supply chains networks, and what strategies enable them to navigate crises?*". By focusing on the narratives and lived experiences of artisans, this inductive approach ensures that the emergent theoretical framework is firmly grounded in participant perspectives. This direct linkage between the Gioia methodology and the research objectives underscores the study's commitment to emergent theory-building, ensuring relevance to both academic and practical contexts.

Research Design

The Gioia methodology was chosen for its capacity to capture participant perspectives and translate them into theoretical insights systematically. Data were collected through 20 semi-structured interviews, balanced between cooperative artisans (10) and traditional business artisans (10). The analysis followed a three-step process:

- o **First-order coding**: Identifying participant-centric terms.
- o **Second-order themes**: Grouping related codes.
- o **Aggregate dimensions**: Synthesizing core theoretical constructs.

Philosophical Stance

Rooted in an interpretivism paradigm, the study views that reality is socially constructed, and we must interpret meanings from participants' perspectives. By emphasizing context and participant perspectives, this paradigm aligns with the Gioia methodology's focus on emergent theory-building.

Data Collection

Data were collected through semi-structured interviews with 20 Moroccan artisans operating within two distinct networks in the Marrakech-Safi region. The interviews were conducted in Moroccan dialectal Arabic and then translated as accurately as possible into English. The sample included ten participants from artisanal cooperatives and ten participants from the business artisanal network. Participants were purposefully selected to ensure diverse perspectives on resilience strategies across these organizational models.

The interview protocol included open-ended questions designed to elicit detailed narratives about the challenges artisans face, the strategies they employ to adapt and thrive in disruptions, and the role of their networks in supporting resilience. Interviews continued until thematic saturation was achieved, ensuring that no new themes or concepts emerged.

Data Analysis

The data was coded using QualCoder, an open-source qualitative data analysis (QDA) software designed for coding, analyzing, and managing qualitative research data, such as interviews, focus groups, and textual documents(Brailas et al., 2023). The analysis followed the three-step process outlined in the Gioia methodology. In the first step, first-order codes were generated by analyzing participant responses to identify descriptive, participant-centric terms reflecting their own language and perspectives. In the second step, these first-order codes were grouped into second-order themes by identifying patterns and relationships. Finally, in the third step, aggregate dimensions were synthesized from the second-order themes to represent the study's core theoretical constructs. A data structure diagram was developed to illustrate the coding hierarchy (Figure 1), from first-order codes to aggregate dimensions, ensuring transparency in the analytical process (Gioia et al., 2013).

Ethical Considerations

Ethical considerations were central to the study. All participants provided informed consent, ensuring their voluntary participation and understanding of the study's purpose. Participant identities and sensitive data were anonymized to maintain confidentiality.

Analysis of Findings

Using the Gioia methodology, our analysis began with the identification of 70 first-order codes derived from the qualitative data. These initial codes captured a wide array of patterns and processes linked to resilience within Moroccan artisanal networks. We then categorized these codes into 30 second-order themes, reflecting broader conceptual groupings.

To ensure relevance to our research question, focused on understanding resilience strategies, we filtered the themes to retain only those most pertinent to resilience dynamics. The final analysis focuses on these refined themes, structured into key aggregate dimensions, to highlight the distinct strategies employed by cooperatives and traditional business networks.

Data structure

As the analysis progressed, similarities and differences among the initial categories were refined through axial coding (Kendall, 1999), reducing them to a manageable set of informant-centered terms. This process bridged raw data and theoretical abstraction, leading to the development of second-order themes and aggregate dimensions (Dufour & Richard, 2019). Constructing the data structure became a pivotal step, visually representing the progression from data to theory and ensuring methodological rigor. Figure 1 illustrates the data structure of the traditional business network, while Figure 2 presents the artisanal cooperative network, highlighting both shared and distinct organizational patterns. However, the data structure is not intended to highlight relationships between second-order themes, as that occurs later in the theorization process. Instead, it fosters a balance between informants' lived experiences and the broader theoretical perspective necessary for academic publication. As a guiding principle, "No data structure; know nothing" underscores its importance (Gioia et al., 2013).
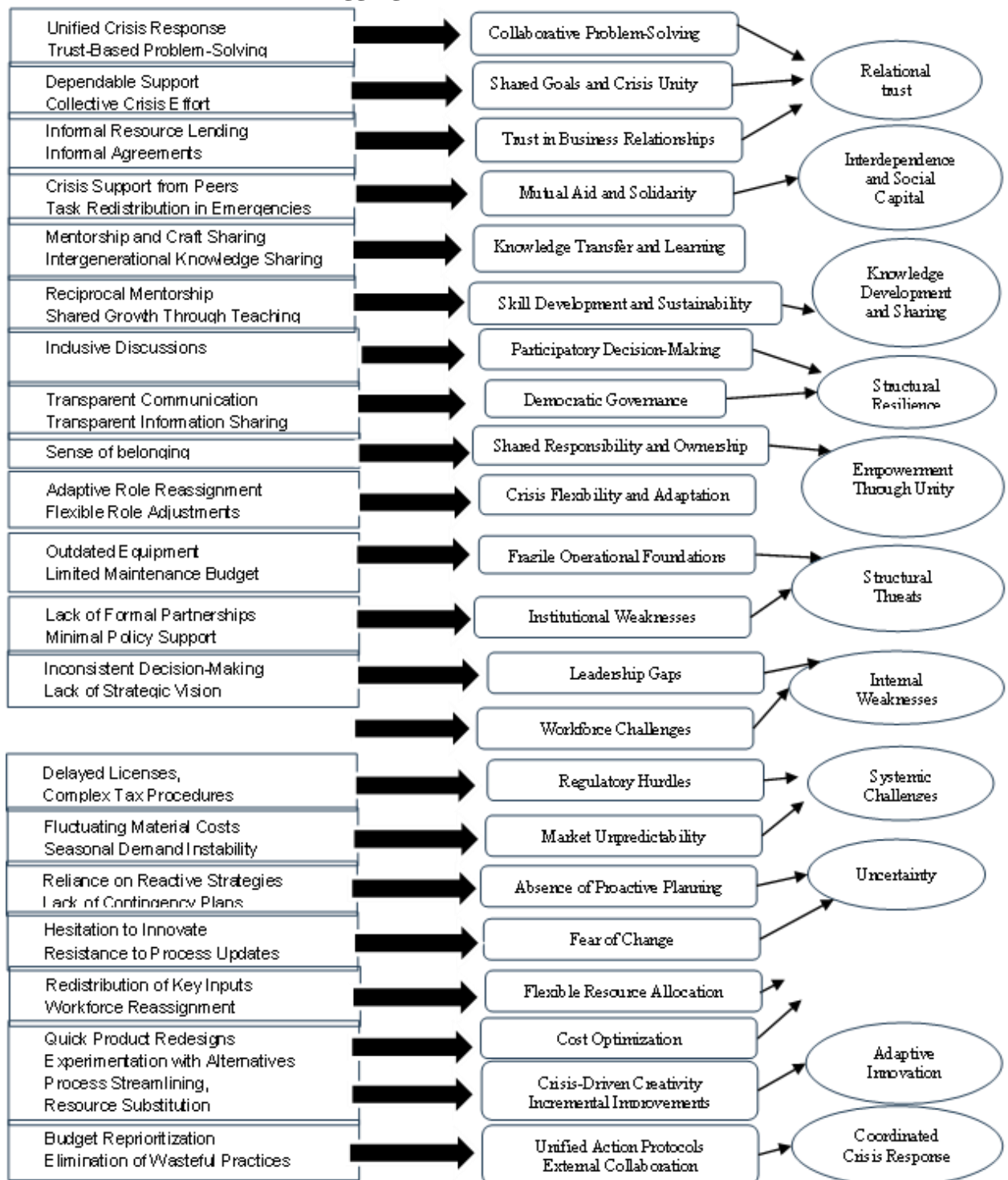
Data structure of the traditional business network
1st Order Concepts Lack of Formalized Processes
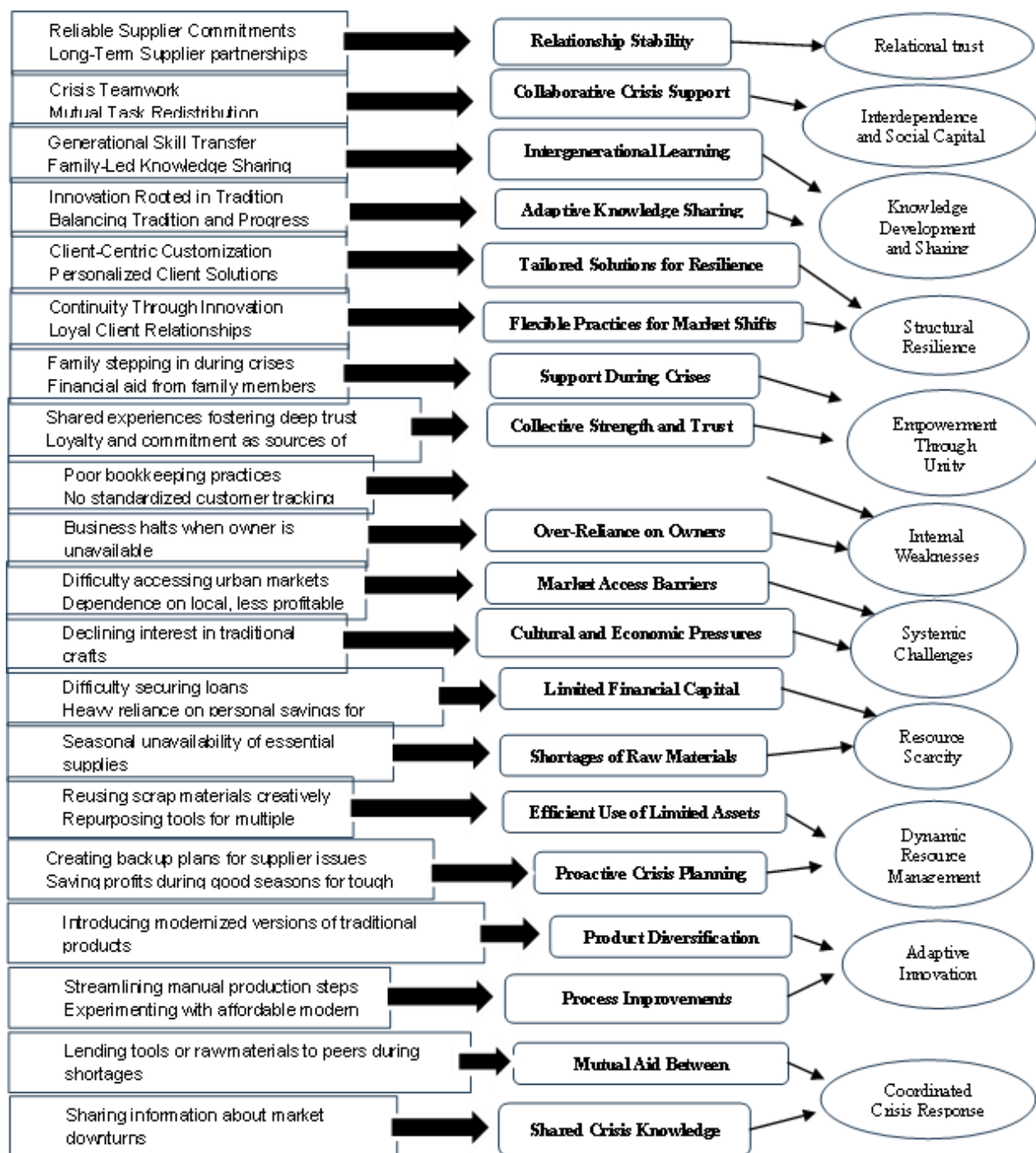
Data structure of the artisanal cooperative network
2nd Order Themes Aggregate Dimensions

From data structure to findings

In this section, we analyze the aggregate dimensions that emerge from the data, emphasizing the key points of divergence between the two networks. To provide a nuanced understanding, we integrate direct quotes from participants where they offer critical insights, allowing their perspectives to illustrate how resilience is constructed and operationalized differently across the networks. While this analysis is structured around the eleven aggregate dimensions in the data analysis framework, direct quotes are selectively included for specific dimensions rather than all, ensuring clarity and relevance while maintaining alignment with the transparency required in the Gioia methodology.

Relational Trust as a Pillar of Resilience
Traditional Business Networks

Traditional business networks anchor trust in personal relationships, built over years of consistent reliability. One artisan, who runs a family business, described the foundation of his success:

> "*I've been working with the same main supplier for over 20 years. He knows my craft, and I know his honesty. When I ran into trouble sourcing materials, he gave me credit without hesitation because he trusted me to pay him back. It's moments like these that keep my business alive.*"

Artisanal Cooperatives

Relational trust within cooperatives is more than just a strategy; it is a deeply rooted ethos. One cooperative artisan recounted a story about a devastating market downturn:

> "*When the pandemic hit, and sales completely stopped, we gathered to talk about what we could do. One of us offered to take a pay cut, the president of the cooperative proposed using the cooperative's limited funds to support members struggling to pay for basic needs and even personally contributed to the shared fund, and others volunteered extra hours to produce new items. It wasn't easy, but knowing we had each other's backs made all the difference.*"

This trust is institutionalized through shared goals, regular member interactions, and collective governance, creating a network that can withstand external shocks by pooling resources and reassigning responsibilities as needed.

Knowledge Sharing and Craft Preservation
Traditional Business Networks

In traditional business networks, knowledge sharing is deeply personal and familial. The owner of the business, visibly emotional, spoke about the legacy of his craft:

> *"My father taught me everything: the skills of the craft, the secrets to perfecting every detail, and the stories behind what we create. Now, I'm teaching my son. It's not just work; it's our heritage. This is how our family has carried on for generations."*

While this generational transmission preserves the essence of the craft, its insularity limits opportunities for external collaboration and innovation, which could enhance adaptability.

Artisanal Cooperatives

Knowledge sharing in cooperatives is a dynamic and collaborative process. One artisan recounted the transformative impact of this system:

> *When I joined the cooperative, I was struggling to make ends meet and didn't know where to start. One of the experienced members sat with me, teaching me not only how to improve my craft but also how to price my work fairly. Over time, I gained confidence and started sharing my own ideas with others. Now, we all contribute in our unique ways, blending innovation with tradition to grow stronger together."*

By institutionalizing mentorship and collaboration, cooperatives ensure that knowledge is continuously updated and shared, creating a resilient foundation for both innovation and tradition.

Structural Resilience and Governance
Traditional Business Networks

In traditional networks, decision-making is typically centralized. The owner explained his approach:

> *"I make all the decisions; it's my responsibility to keep the business running. My workers depend on me, and I can't afford to let them down. However, I sometimes seek the advice of the artisans who have been with us since my father's time, as well as my brothers, who receive a share of the profits. But in the end, the final decision is always mine."*

While this structure enables quick responses, it also concentrates risks. If the central decision-maker is unavailable or overwhelmed, the business may struggle to adapt.

Artisanal Cooperatives

Cooperatives operate with democratic governance, ensuring that all members have a voice. One artisan shared:

> *"When we face a challenge, we sit down as a group. Everyone speaks, even the youngest member. The solution we choose is always better because it comes from everyone's ideas. And when it works, we all feel proud because it's our collective decision."*

This inclusivity, paired with flexible task distribution, allows cooperatives to adapt rapidly to crises, reinforcing their resilience.

Empowerment Through Unity
Traditional Business Networks

In traditional business networks, empowerment stems from personal bonds and a sense of loyalty built over years of shared experiences. The owner may take on the main responsibility, but the strength of the business often lies in the relationships cultivated over time. The owner, with visible emotion, shared:

> *"When my father passed away, the business went through many difficulties. I felt the weight of the world on my shoulders. I was responsible for everything our workers, our clients, our reputation. But then my brothers stepped in. They didn't ask for anything; they just said, 'We're here for the business.' Even though each of them had a career far from craftsmanship, one was an engineer and the other a teacher. One of them lent me money to keep things running, and another worked alongside me every evening to finish orders. In that moment, I realized that while I make the final decisions, it's their support that keeps me going. This business isn't just mine - it's ours."*

While decision-making is often centralized, moments of crisis reveal the true strength of traditional networks: the unshakable trust and commitment of those closest to the business. This personal loyalty creates a safety net, even if it lacks the formal structure of a cooperative.

Artisanal Cooperatives

In cooperatives, empowerment comes from the shared belief that every member matters and that strength lies in unity. When crises arise, members don't just look out for themselves; they rise together. One artisan reflected passionately on the power of this unity:

> *"I remember when one of our members received the devastating news that he had lost his father in the Asni earthquake. He was shattered, unable to focus on anything. We*

didn't hesitate - we took over his work, completed his orders, and ensured his income didn't stop while he grieved. Later, he told me, 'You didn't just help me keep my livelihood; you reminded me that I wasn't alone.' That's what being in a cooperative is about: standing together, no matter how hard it gets. We're not just colleagues; we're family."

This ethos of shared responsibility and mutual support goes beyond practical solutions - it creates a deep sense of belonging and trust. The flexibility to reassign roles and tasks ensures that no single person carries the burden alone, making the cooperative not just resilient but transformative for its members.

Internal Weaknesses
Traditional Business Networks

For traditional businesses, internal weaknesses often arise from dependency on a single decision-maker or lack of succession planning. The owner confessed:

"*My father was the backbone of this business. When he passed away, I realized how much we depended on him for everything - from managing finances to dealing with clients. I had to learn everything on the job, and it almost broke me."*

This centralized structure, while efficient for quick decisions, can leave the business vulnerable during transitions or crises if knowledge and responsibilities are not distributed effectively.

Artisanal Cooperatives:

Internal weaknesses in cooperatives often stem from their collective decision-making processes and varying levels of member commitment. One artisan shared their frustration:

"*Sometimes, we spend so much time in meetings, debating every little thing. Some members don't show up consistently, yet they expect an equal share of the profits. It's hard to build momentum when not everyone is pulling their weight.*"

This democratic structure, while inclusive, can slow decision-making and lead to inefficiencies when all members are equally engaged. Addressing these weaknesses requires stronger enforcement of member responsibilities and clearer systems of accountability.

Systemic Challenges
Traditional Business Networks

For traditional businesses, systemic challenges frequently relate to market volatility and competition. One artisan lamented:

"*When larger companies started selling cheaper, machine-made versions of our craft, we lost some important customers almost overnight. Competing on price is impossible for a small, family-run business like ours*."

This lack of competitive leverage underscores the need for traditional businesses to adapt and innovate while preserving their unique identity in a rapidly changing market.

Artisanal Cooperatives

Systemic challenges for cooperatives often revolve around navigating bureaucratic hurdles and accessing institutional support. One cooperative leader explained:

"*We applied for government and the Office for Cooperative Development support during the pandemic, but the process was so complicated. Weeks turned into months, and by the time we received the funds, we had already found other ways to survive. It feels like the system isn't designed for groups like ours.*"

Despite their collective strength, cooperatives often face delays and inefficiencies when dealing with external systems, highlighting the need for streamlined institutional support tailored to their unique structures.

Adaptive Innovation
Traditional Business Networks

For traditional businesses, innovation often emerges from necessity. One artisan shared:

"*I started making custom designs based on customer requests. It's more work, but it's what sets me apart from larger competitors. People appreciate the personal touch*."

This focus on customization and individual relationships enables traditional businesses to remain competitive, though it may limit scalability compared to cooperative innovations.

Artisanal Cooperatives

Cooperatives embrace adaptive innovation by blending traditional techniques with modern approaches. One artisan explained:

"*We found new ways to share our expertise and attract customers by diversifying our craft demonstrations and workshops. It was a step into the unknown, but it helped us expand our reach and sustain our work.*"

This openness to experimentation allows cooperatives to innovate while staying true to their roots, enhancing both resilience and growth.

The Role of Network Design in Resilience

The analysis underscores the critical influence of *network design* on resilience mechanisms:

Traditional Business Networks: These networks are structured around tight-knit, personalized relationships, where decision-making is centralized and knowledge is passed down within families. This design allows for quick responses to challenges but also creates fragility, as resilience depends on a few key individuals. If these individuals exit the network or face disruptions, the entire structure is at risk due to its reliance on informal, relationship-based support.

Cooperative Networks: Designed around shared governance and collective resource management, cooperative networks embed resilience through distributed decision-making and mutual aid. This structure reduces dependency on any single member, ensuring that disruptions are absorbed collectively. The cooperative model fosters adaptability by institutionalizing collaboration, enabling artisans to respond flexibly to crises and sustain long-term operations.

Dynamic conceptual framework

As part of this study's findings, we developed a **Dynamic Conceptual Framework** (Figure 3) to explain the resilience mechanisms found within **Moroccan artisanal networks**. Resilience in these networks is not a fixed trait but an **ongoing, adaptive process** shaped by crises, internal tensions, and strategic responses. **Grounded in the Gioia methodology**, this framework reveals resilience as a **continuous interaction between disruptive forces, network vulnerabilities, and adaptive mechanisms**, leading to either **network stabilization** or **persistent stress**.

At the core of this framework, Moroccan artisans rely on **relational trust, embedded knowledge transmission, and informal social safety nets** to counteract structural threats, financial instability, and workforce challenges. These mechanisms, in turn, enable **strategic responses** such as **emergency mutual aid, skill redistribution, and sourcing diversification**, ultimately guiding the network toward a **resilient state**.
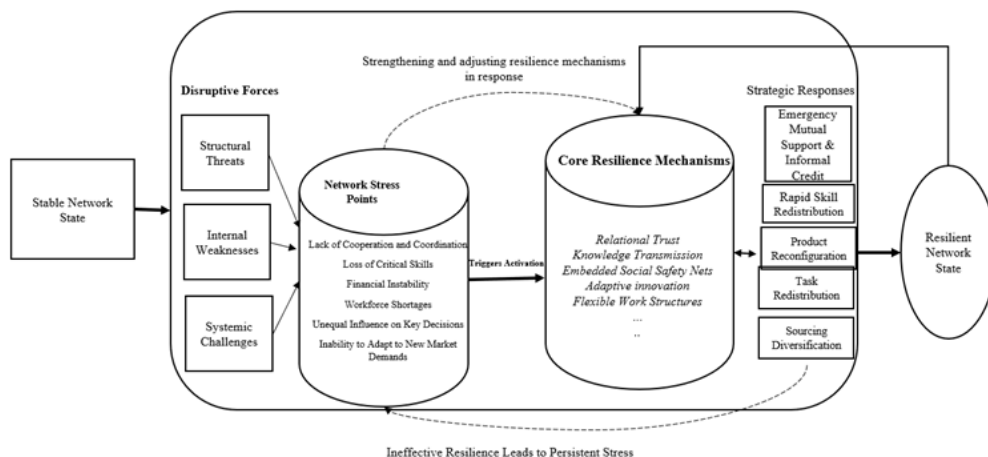
Figure 3: Dynamic conceptual framework

Discussion

This study makes a significant theoretical contribution to the resilience literature by demonstrating that both cooperative and traditional business networks share common resilience mechanisms, including relational trust, knowledge transfer, and resource adaptability. However, the network design fundamentally shapes how these mechanisms operate, particularly through variations in governance structures, decision-making processes, and resource coordination. By applying an inductive research approach using Gioia's methodology, this study advances theoretical understanding of resilience as a dynamic and network-dependent process.

Shared Resilience Mechanisms

This study identifies three primary resilience mechanisms that are common to both cooperative and traditional business networks, supporting the idea that resilience emerges from structural and relational attributes rather than network type alone.

Relational Trust as a Foundation for Resilience

Relational trust serves as a central pillar of resilience in both types of networks. Trust facilitates collaborative problem-solving, mitigates uncertainty, and enhances the ability to respond to external disruptions. Uzzi (1997)argues that embedded ties foster mutual assistance and joint risk-taking, which aligns with the role of trust in both cooperative and traditional business networks. Nahapiet & Ghoshal (2009b) emphasize that trust enhances the exchange of intellectual capital, reinforcing how trust-based relationships sustain resilience in turbulent environments.

However, the form and institutionalization of trust differ. In cooperatives, trust is formalized and institutionalized through collective decision-making processes (Adler & Kwon, 2002; Felin & Foss, 2005), whereas in traditional business networks, trust operates through informal, dyadic relationships and long-term reputational effects (Burt, 2000; Granovetter, 1985).

Knowledge Transfer and Adaptive Learning

Both networks exhibit knowledge sharing as a resilience-enhancing mechanism, aligning with organizational learning and absorptive capacity theories (Cohen & Levinthal, 1990; Zahra & George, 2002). Knowledge diffusion and transfer enables networks to respond to crises dynamically, leverage collective intelligence, and integrate market and operational insights to maintain stability.

Cooperatives rely on formalized knowledge-sharing structures through participatory governance (Hamel, 1991; Levinthal & March, 1993) , while traditional business networks engage in informal, experience-based learning through embedded social ties (Lane et al., 2006; Reagans & McEvily, 2003). The ability to absorb and apply external knowledge ensures that both networks remain agile and responsive to external.

Resource Adaptability

The ability to reconfigure resources to adapt to environmental changes is a hallmark of resilience. This aligns with the dynamic capabilities framework (Eisenhardt & Martin, 2000; Teece et al., 1997b), which emphasizes that firms that can reconfigure assets in response to crises are more likely to survive and thrive.

Both cooperative and traditional business networks demonstrate resource adaptability, although through different mechanisms. Cooperatives utilize collective pooling of resources and mutual aid systems (Ostrom, 1990; Williamson, 1985), while traditional business networks leverage market-driven flexibility and strategic partnerships (Dyer & Singh, 1998; Lavie, 2006)

Governance Structures and Decision-Making

The governance structure dictates how resilience mechanisms operate (Jones et al., 1997; Provan & Kenis, 2008).

Cooperative networks exhibit democratic governance and collective decision-making, which enhance resilience through distributed leadership and shared responsibility (Adler & Kwon, 2002; Ostrom, 1990). While traditional business networks have centralized decision-making structures, allowing for faster crisis response but with less participatory problem-solving (Mintzberg, 1979).

Theoretical Contributions and Implications

This study advances resilience theory by demonstrating that resilience is not solely a function of network type but of how resilience mechanisms operate within different network designs. The findings contribute to several theoretical domains:

Organizational Resilience Theory: This study extends resilience research by showing how resilience mechanisms function in different governance structures.

Network Theory and Social Capital: It integrates insights from network embeddedness and social capital theories (Burt, 2000; Granovetter, 1985) to explain how relational ties shape adaptive capacity.

Dynamic Capabilities Perspective: By linking resilience mechanisms to resource reconfiguration and learning capabilities (Eisenhardt & Martin, 2000; Teece et al., 1997) , it emphasizes how networks sustain competitive advantage under crisis conditions.

Limitations and Future Directions

While this study provides valuable insights into resilience within Moroccan artisanal supply chain networks, several limitations warrant consideration.

First, the study's sample size of 20 interviews - equally split between cooperative and traditional business artisans - offers rich qualitative depth but limits the broader applicability of findings. While sufficient for an interpretive, theory-building approach, this sample may not fully capture the diversity of resilience strategies across different regions, industries, or supply chain structures. Future research could expand the sample to include artisans operating in hybrid or state-supported networks, enhancing the external validity of the findings.

Second, the cross-sectional design captures resilience at a single point in time, overlooking how resilience mechanisms evolve in response to long-term disruptions and market shifts. Given that resilience is a dynamic and adaptive process, longitudinal research could provide deeper insights into how artisans sustain or modify their strategies over time.

Finally, while the study is grounded in network embeddedness, social capital, and dynamic capabilities perspectives, resilience in artisanal networks may also be shaped by other theoretical dimensions, such as institutional logics, resource dependency, or community-based entrepreneurship. Expanding the theoretical scope could offer a more comprehensive understanding of how governance structures and external institutional forces influence resilience.

Despite these limitations, this study lays a strong empirical and theoretical foundation for understanding resilience in informal supply chain

networks. By highlighting the distinct yet interrelated resilience mechanisms shaping cooperative and traditional business networks, it advances discussions on how small-scale enterprises navigate uncertainty, sustain their livelihoods, and adapt to changing market conditions. Addressing these limitations through comparative, longitudinal, and multi-method research will further refine and expand resilience theory in the context of artisanal supply chains.

Conclusion

This study provides a fresh perspective on resilience strategies within Moroccan artisanal supply chains, emphasizing how cooperative and traditional business networks navigate disruptions. Using the Gioia methodology, we developed a Dynamic Conceptual Framework that redefines resilience as an adaptive, evolving process shaped by crises and strategic responses.

Our findings framework demonstrates how resilience mechanisms, trust, knowledge transfer, and empowerment, etc.. interact dynamically, strengthening or weakening resilience over time. A key contribution of this study is the Dynamic Conceptual Framework, which maps how networks transition between stability and crisis, identifying stress points such as power imbalances and resource constraints. This framework advances resilience theory by showing that artisans do not passively endure crises but actively reshape their networks and strategies to sustain their livelihoods and cultural heritage.

From a practical perspective, fostering hybrid resilience strategies that combine structured cooperation with entrepreneurial flexibility is essential. Policymakers should support both network types through digital integration, financial aid, and improved market access.

By shifting resilience discourse from corporate supply chains to the artisanal sector, this study provides valuable insights for future research. Longitudinal studies should further examine how resilience mechanisms evolve in response to economic, environmental, and technological changes, ensuring that artisanal networks remain both sustainable and transformative.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the qualitative nature of the research and confidentiality agreements with participants, full transcripts and raw data cannot be publicly shared. However, summarized insights and anonymized excerpts can be provided upon request, subject to ethical considerations.

Declaration for Human Participants: The study was conducted as part of doctoral research at Mohammed V University of Rabat, Faculty of Legal, Economic, and Social Sciences – Souissi, within the Research Laboratory in Management of Organizations, Business Law, and Sustainable Development. Although no formal ethics committee approval was obtained, all interviews were carried out with the informed consent of participants. The research adhered to ethical standards, including respect for participant confidentiality, anonymity, and voluntary participation, in accordance with the principles of the Helsinki Declaration.

Note on Theoretical Framework: While this study draws on previous research to establish its relevance, it is not guided by a predefined theoretical framework. Instead, it adopts an inductive and exploratory approach to uncover context-specific insights.

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Navigating Digital Transformation in E-learning at Bangladesh's Tertiary Level: Prospects and Challenges

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Abstract

In the 21st century, Higher Education Institutions have prioritized digital shift as an apparent and essential process for their institutions. In the face of the growing importance and demands of digital incorporation into the classroom and examination process, the HEIs in Bangladesh continue to impart online education even after the pandemic. Having this backdrop, the present research aims to identify the challenges that the HEIs in Bangladesh are facing in implementing digitalization. Since the present study aims to respond to the research questions of a qualitative and quantitative nature, data collection and analysis techniques from both methodologies are implemented, and the Mixed Method Research approach has been chosen as the methodology of this research. The study employed convenient sampling and involved a total of 100 students - 50 from two public universities and 50 from two private universities in Bangladesh. Additionally, we included 10 teachers, with an equal distribution of 5 from public and 5 from private universities. Data was gathered through written survey questionnaires and interviews conducted with the participants. The study's findings revealed several significant challenges faced by higher education institutions (HEIs) in Bangladesh as a result of digital transformation. Key issues include a lack of a clear strategic vision (50%), inadequate policy and legislative frameworks (45%), insufficient digital literacy among stakeholders (83%), unreliable internet connectivity (33%), ineffective outcome-based digital teaching and learning platforms (67%), and serious concerns regarding digital campus network information security (83%). Additionally, financial constraints

(67%), limited technological support (67%), insufficient data enablement solutions (48%), underutilized artificial intelligence capabilities (49%), and a scarcity of digital academic library resources (63%) further exacerbate the situation. To address these challenges, the study offers several recommendations. These include formulating a strategic vision for digital transformation and modernizing the curriculum and Learning Management Systems (LMS). Furthermore, a proposed framework for "digital maturity" is put forth, enabling HEIs to evaluate their current digital strategies and improve them through the integration of various enterprises and methodologies.

Introduction

In the 21st century, higher education institutions (HEIs) recognise the digital shift as a crucial and inevitable evolution for their organizations. The third technological knowledge revolution, often referred to as the "digital revolution" (Benavides, Arias, Serna, Bedoya & Burgos, 2020, p. 1), serves as the foundation for the burgeoning landscape of information and communication technology. This transformation is reflected in the changing patterns of production, exchange, and services. Digital transformation is pivotal in modernizing broadcasting systems and reshaping the methods of knowledge delivery and education (as-Saudi, 2019). It also brings about significant changes in the dynamics of academic institutions and their environments, thus narrowing the digital divide and emphasizing the transition towards digital universities. Consequently, universities must adapt to the evolving variables and demands of this new reality (Ben Naji, 2020). In recent years, various technological advancements have propelled a surge in innovative educational projects focused on digital transformation within higher education. These initiatives represent genuine models of renewal for universities (Menendez, Machado & Esteban, 2016). In this landscape, HEIs have set objectives to modernize their approaches, implementing strategies to enhance and fully leverage digital capabilities while laying the legislative and technical groundwork (Madhi & Abu Hajeer, 2020). This shift has positioned these institutions within the digital revolution. Much like any transformative era, digital transformation requires a reorganization of structures and sectors, ultimately leading to profound changes in university operations (al-Balochia, al-Harasi, & al-Awfi, 2020). These ongoing changes highlight how the rapid integration of new media technologies and vast data volumes generates a notable level of unpredictability in daily organizational practices.

Digitization facilitates Higher education institutions (HEIs) to shift their resources and operations to cloud-based platforms or virtual networks,

broadening access for more individuals while helping to manage costs and reduce environmental impact. The core aim of digital transformation in HEIs should be to redefine educational tools and enhance operational processes (Bond et al., 2018). Big data empowers graduates to explore new teaching methodologies while adapting to personalized learning experiences. University planning must evolve in tandem with digital advancements (Bond et al., 2018), as it is not just about enhancing teaching methods but also about adapting internal processes to better reflect the needs of both students and educators.

Therefore, the learning management system of educational institutions faces the challenges of sustaining because knowledge is exceeded continuously by evolving technologies (Bond et al., 2018). In addition, as digital transformation leads to practical and creative instruction and trust in artistry and entrepreneurship, it increases the educational and creative coverage of organizations (al-Balochia et al., 2019). As a result of a growing number of challenges, HEIs should blend digital technologies into their trade much with more reason than before. This will bring major changes in HEIs' work and how they deliver value to their stakeholders.

During the COVID-19 pandemic, online education all over the world has gone through an explosion. The world's renowned universities offered full-fledged degrees on platforms like edX and Coursera. Though these programmes have not replaced traditional classroom learning, they have provided alternative ways for the students. It has not only provided quality education but also saved time, budget, and distance. Like other parts of the world, online education has come a long way in becoming accessible in Bangladesh at all levels of education. We faced many problems during the pandemic period. The whole world has come to a standstill in the Corona crisis; naturally, our education system was also stagnant there. Many were bored and frustrated while sitting at home, just as many were suffering from the uncertainty of getting food daily.

Even in that grave situation, the initiatives that were taken by the HEIs ensured the digitalization of education in classrooms. However, it has not been extended beyond the classrooms. Research (Bashir, Uddin, Basu, and Khan, 2021) shows that the public universities in Bangladesh faced several challenges to the successful implementation of online instruction during the COVID-19 situation. The challenges we have identified include access to technology, affordability, the ability to effectively use technology, teaching methods, availability of online study materials, assessment processes, and ensuring equity (Papachashvili, 2021). The stakeholders also have a lack of training on digital devices. Thus, a complete transformation of digitalized education has not been possible

In the face of the growing importance and demands of digital incorporation into the classroom and examination process, the HEIs in Bangladesh continue to impart online education. Considering that as a backdrop, the objective of this research is to uncover the constraints that Higher Education Institutions (HEIs) in Bangladesh encounter while trying to implement digitalization. It also intends to provide a likely solution to education professionals on how to transform their educational institutions.

Statement of the Problem

As digital adoption becomes more competitive for educational organizations, we have started to apprehend the extensive power of education-driven technology during the pandemic. To meet the demands of the digital age, educators need to explore additional methods for incorporating technology into their teaching practices. After the pandemic, almost all institutions throughout the world had to switch to distance learning. Though all of them faced challenges due to distance learning, which is also the same for hybrid learning in some countries, it cannot be ignored that the need to step up digitalization is inevitable. Higher educational institutions like the universities have more potential to manage this than others.

In the face of the growing importance and demands of digital incorporation into the classroom and examination process, the HEIs in Bangladesh continue to impart online education. The government of Bangladesh is instrumental in advancing the digital transformation of higher education through a variety of supportive measures, including policy frameworks, funding, and infrastructure development (UGC, 2018). These efforts encompass policies aimed at enhancing internet access, promoting ICT education, and fostering e-governance, as seen in initiatives like the Digital Bangladesh vision. With governmental backing, universities and educational institutions are better equipped to integrate technology, launch digital literacy programs, and boost their research capabilities (UGC, 2018). Furthermore, the Strategic Plan for Higher Education (SPHE) 2018-2030 outlines a clear strategy for modernizing higher education with a strong emphasis on technology (UGC, 2018). The Master Plan for ICT in Education (2012-2021) was designed to facilitate teaching and learning through technology (MoE, 2019).

Researchers appropriately identify that further study should be conducted to find the impact of digital transformation on the HEIs in of theoretical and practical terms (Benavides et al., 2020). Though there are many research works conducted on DT during and after the pandemic (Sultana, 2022; Khan, Jahan, Sultana, Kabir, Haider, & Roshid, 2021; Khan, Bashir, Basu, & Uddin, 2020; Khan, Basu, Bashir & Uddin, 2021; Bashir, Uddin, Basu, Khan, Hardiyanti, Nugraheni, & Jemadi, 2021), very limited research

works have been conducted on the digital transformation in Bangladesh. Having this backdrop, the current study seeks to uncover the hurdles that higher education institutions (HEIs) in Bangladesh are encountering in their efforts to embrace digitalization. It also intends to provide probable solutions to education professionals on how to transform their educational institutions.

Objectives of the Study
Broad Objective
The main objective of this research is to pinpoint the challenges faced by Higher Educational Institutions (HEIs) in the era of increasing digitalization and to offer recommendations for education professionals on how to effectively transform their institutions. Consequently, the study centres on the following specific objectives.

Specific Objectives
- o To ascertain the extent to which the digital transformation practices and strategies are working in the HEIs in Bangladesh.
- o To examine the obstacles faced by Higher Education Institutions (HEIs) in adopting e-learning in the context of growing digitalization.
- o To provide a guideline to the education professionals on how to transform their educational institutions and assist in the incorporation of different initiatives and approaches.

Research Questions
The gap in the literature leads to the exploration of the following research questions:
- o What is the current state of digital transformation practices and strategies of HEIs in Bangladesh?
- o What challenges do Higher Education Institutions (HEIs) face in light of the rising trend of digitalization?
- o How can we customize a guideline to help higher education institutions (HEIs) evolve and effectively integrate various initiatives and approaches to digital transformation?

Research Methodology
The current study sought to answer a blend of qualitative and quantitative research questions, leading to the use of data collection and analysis techniques from both methodologies. As a result, we adopted a Mixed Methods Research (MMR) approach for this study. The study employed convenient sampling (Popham, 1993) and involved a total of 100 students - 50 from two public universities and 50 from two private universities in Bangladesh. All the participants have experience with both online and offline

courses at the tertiary level in Bangladesh. Additionally, we included 10 teachers, with an equal distribution of 5 from public and 5 from private universities. All of them have more than two years of experience teaching on both online and offline platforms. Due to the large and unknown population size and the limited number of universities providing e-learning options in Bangladesh, samples were sourced exclusively from universities that currently offer e-learning or are on the brink of digital transformation. To ensure a representative sample, participants from both public and private universities were included. Data was gathered through written survey questionnaires and interviews conducted with the participants. The questionnaire was based on the literature review about digital transformation in HEIs and was developed by the researcher. It was divided into two sections and had 30 items. The items included in the questionnaires focused on the major concerns related to digital transformation in HEIs. For this study, semi-structured interviews have been used.

All questionnaires were completed during face-to-face classes. Students took approximately 50 minutes to respond, while teachers spent around one hour answering the questions. The data collection was conducted without interference from teachers or the researcher, ensuring the reliability of the findings. Once collected, the scripts were processed for analysis and interpretation.

Each interview lasted about thirty minutes and consisted of open-ended questions related to various aspects of Digital Transformation (DT) and its implementation in Bangladesh. Participants were encouraged to review the questions briefly before the interview began, making it clear that the interviewer might ask additional questions based on their online questionnaire responses. Further inquiries could emerge during the discussion, depending on how the interviewees responded. Participants were also assured they could freely express their thoughts and share any pertinent information, and were under no obligation to answer any questions they found uncomfortable. Closed-ended questions were deliberately avoided, with most inquiries focusing on teachers' perceptions and experiences in implementing DT practices in the Bangladeshi context.

An informed consent form was included at the start of the survey to ensure participants were fully aware of the study's nature and objectives, along with their rights. They were informed that participation was entirely voluntary, and any identifiable information would remain confidential unless permission was granted for its disclosure. It was explicitly stated that there were no known physical, psychological, social, or legal risks associated with the study beyond those encountered in everyday life.

The survey data were processed using Excel, and descriptive statistics were applied for analysis, with findings presented using frequencies and

percentages. Qualitative data were transcribed and analysed based on major themes. Data analysis utilized four measurement scales (nominal, ordinal, interval, and ratio), with the Likert scale employed for itemized rating. Reliability means, in the measurement context, two issues concurrently: repeatability and consistency of result from a measurement. The Questionnaire used for this study is compared with some similar questionnaires to the same ends and produces more or less similar result. It happens in terms of palace and time. Such study as Sarkar (2002; Katrin 2002). Therefore, it can be attributed that the measurement used for this study is reliable.

Results and Discussion
Teachers' and Students' Opinion about Digital Transformation
Capacity and Challenges of the HEIs for Digitalization

Has your institution arranged any workshop or training for the students on different features of online learning?
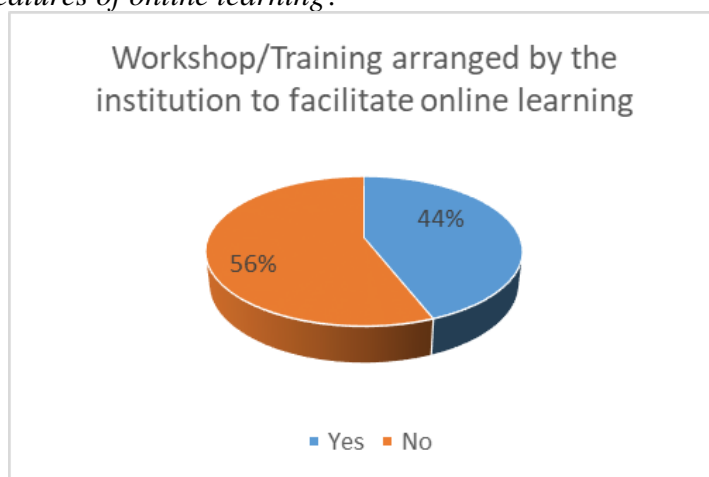
Chart 1: workshop/training arranged by the institution to facilitate online learning

The above chart shows most of the students (56%) asserted that there were no workshops/trainings on online learning have been arranged by their institutions. However, 44% of students confirmed that their institution arranged workshops/training to facilitate online learning which is quite encouraging.

Has your institution arranged any workshop or training on different features of online teaching?
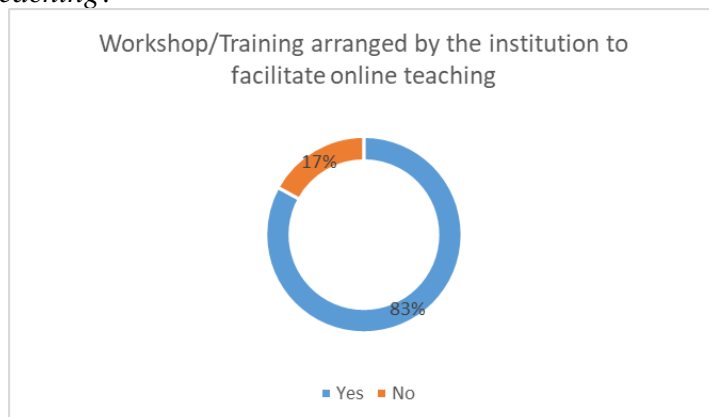
Chart 2: workshop/training arranged by the institution to facilitate online teaching

Most of the teachers (83%) asserted that they received workshops/training on online teaching arranged by their institution while some of them (17%) commented negatively.

Do your institution have policy and legislative frameworks, rules and norms to conduct online classes?
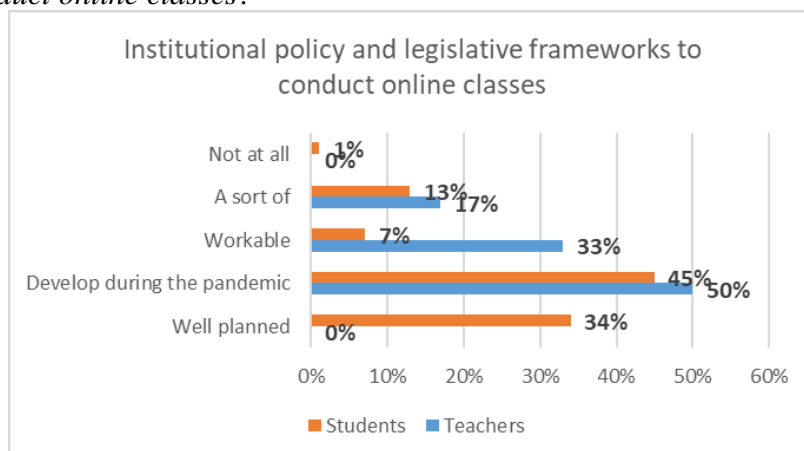
Chart 3: institutional policy and legislative frameworks, rules and norms to conduct online classes

The above statistics show that almost half of the students (45%) and teachers (50%) gave the opinion that during the pandemic, the online policy has developed, while 34% of students consider it well-planned. But a good number (33%) of teachers consider it workable and 13% of students and 17% of teachers think a sort of policy is there, while 1% of the students are totally negative in this respect.

Does your institution have support structures, equipment, and finances?
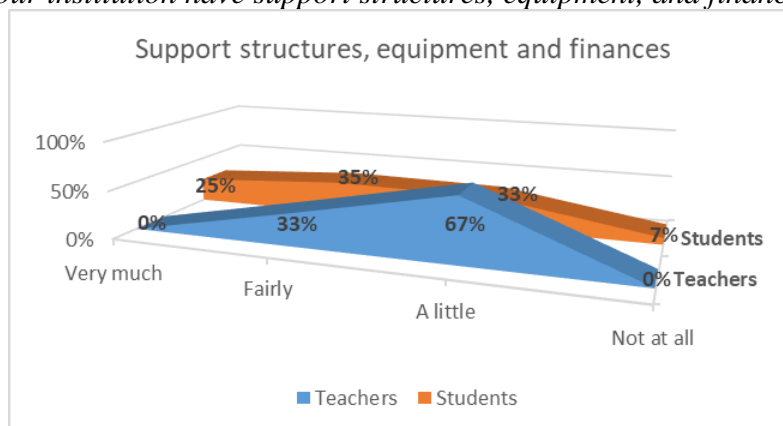
Chart 4: support structures, equipment, and finances

The statistics show that 25% of students claim that their institutions have enough support structures, equipment, and finances to conduct online classes. An almost similar number of students (35%) and teachers (33%) suggest that it is fairly enough. However, most of the teachers (67%) and 33% of students report that the support structure is little. And 7% of learners think that there is no support structure.

Does your institution have enough technical staffs to support e-learning?
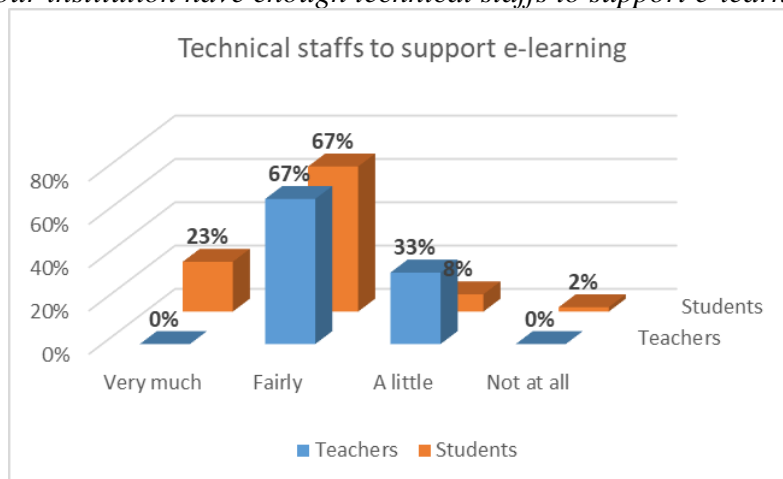
Chart 5: technical staffs to support e-learning

On the issue of technical staff to support e-learning, most (67%) of the students and teachers respond that their institutions have fairly enough technical staff to support e-learning; 23% of students consider it moderate, while 33% of teachers and 8% of students think it is not adequate. And 2% of them think that there are no technical staff to support e-learning.

Do you receive any formal and informal incentive from your institution for conducting online classes?
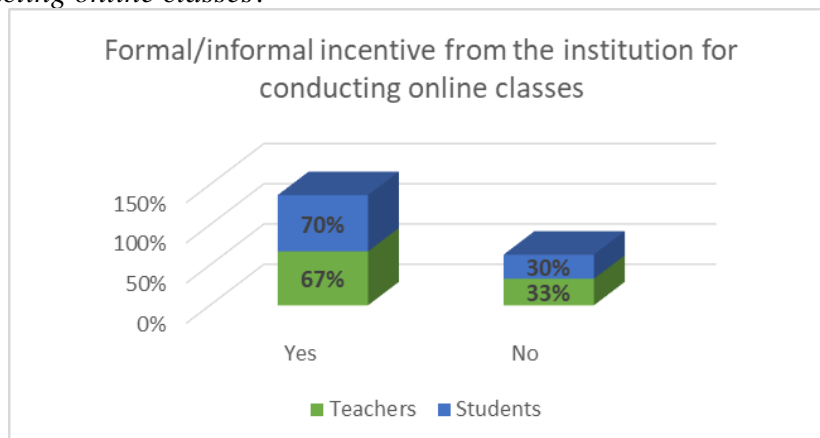
Chart 6: formal/informal incentive from the institution for conducting online classes

Almost all the teachers (67%) and students (70%) admit that they received both formal and informal incentives from the institution for conducting online classes. However, one-third of them stated that they did not receive any incentive.

Do you have any previous knowledge and expertise in online classes?
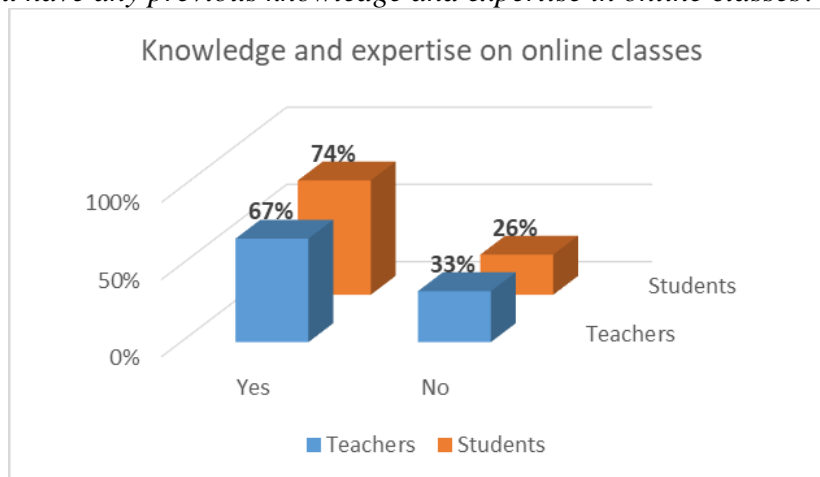
Chart 7: knowledge and expertise on online classes

It has been evident that a good number of students (74%) and teachers (67%) have the knowledge and expertise in online classes after the pandemic.

That means during the pandemic, they became familiar with online teaching and learning. However, it also reveals that one-third of the population has not been exposed to online classes.

Rate your technological skills for online learning.
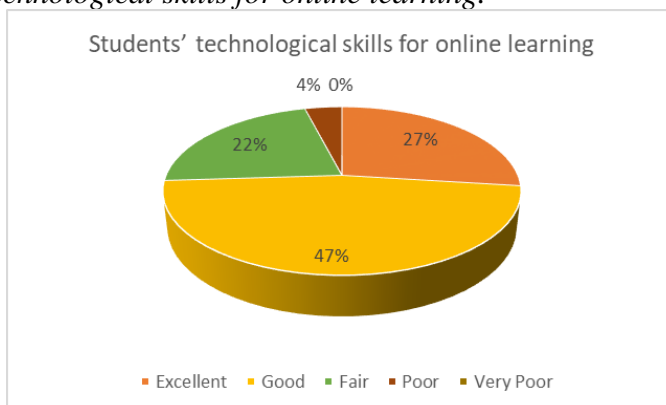
Chart 8: students' technological skills for online learning

47% of students responded that their technological skills for conducting online classes are good and 27% of them commented that it is excellent, while 22% said it is fair. However, 4% of students admitted that they are not technologically sound.

Rate your teachers' technological skills for online teaching.
Rate your technological skills for online teaching.

50% of students responded that their teachers' technological skills for conducting online classes are good while 33% of the teachers themselves consider it good. Similarly, 25% of students commented that their teachers' technological skills are excellent whereas 17% of teachers consider that their technological skill is excellent.
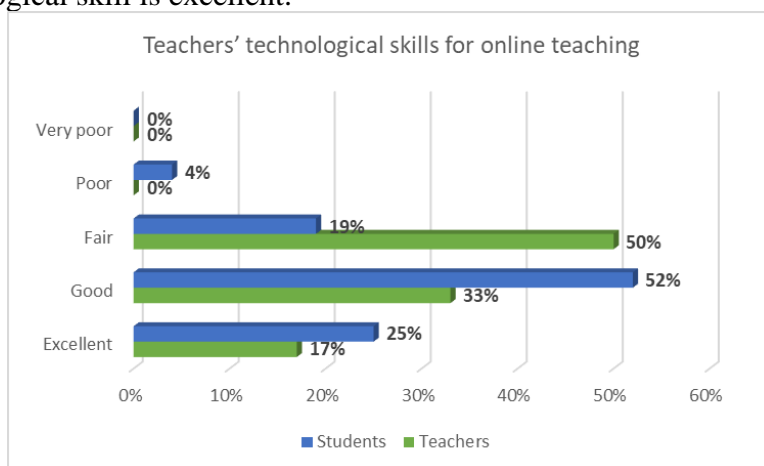
Chart 9: teachers' technological skills for online teaching

Interestingly, 50% of teachers consider that their technological skill is fair while 19% of students consider it fair. However, 4% of students demand

that their teachers are technologically poor. Therefore, there is a similarity between students' assessments and teachers' claims.

Do you have the necessary technological devices to support your online learning? Do you have the necessary technological devices to support your online teaching?

The below bar chart shows that 67% of teachers, and 41% of students have adequate technological devices to support online teaching/learning while 33% of teachers and 44% of students comment that they have workable technological devices to take online classes.
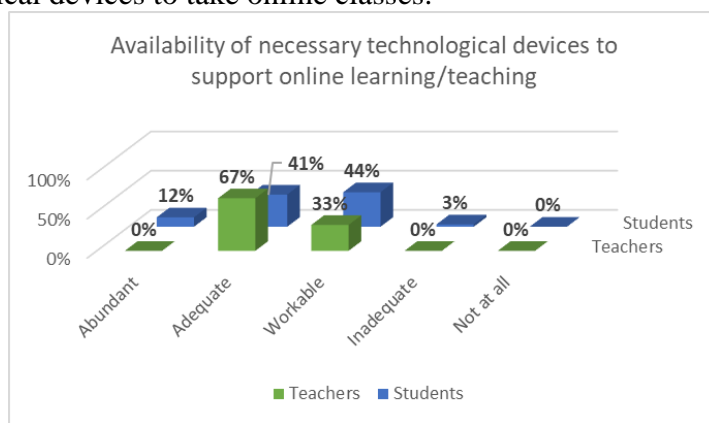
Chart 10: Availability of necessary technological devices to support online learning/teaching

However, 3% of the students have inadequate technological support though 12% have abundant. The result shows that though the teachers and students have technological support still it is not up to the standard for digital transformation.

How is the quality of your internet connection?
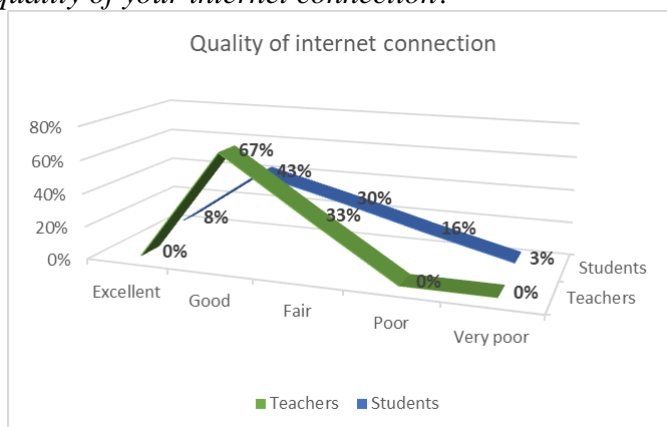
Chart 11: quality of internet connection

The above chart shows that a maximum number of students (good-43% + fair-30% = 73%) have a good internet connection, while 16% of them comment that the internet connection is poor and 3% consider it very poor. Only 8% of students are having excellent, uninterrupted internet connection. On the other hand, 67% of teachers comment that they have a good internet connection while 33% consider it fair.

Does your institution have a digital academic library?
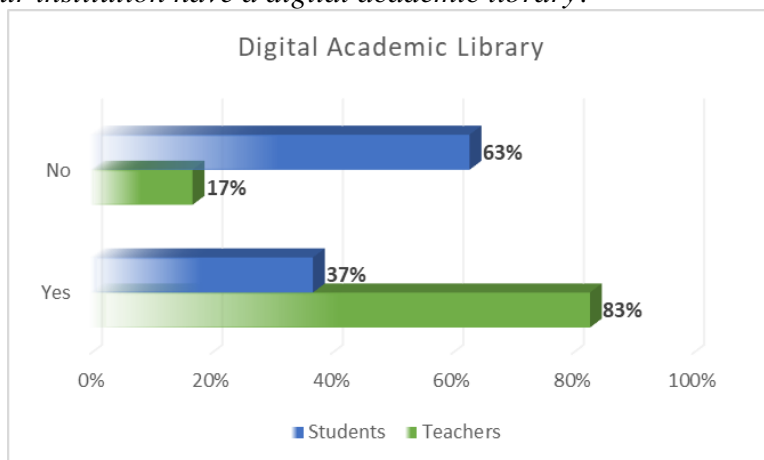
Chart 12: digital academic library

The above bar chart shows interesting statistics. While a maximum number of students (63%) comment that their institutions do not have a digital academic library, most of the teachers (83%) comment that the institutions have a digital academic library.

Parameter of Digitally Transformed Campus
Does your institution provide the following services to create a digitally transformed campus?
Please indicate your opinion in the following areas. Tick (√) appropriate boxes.

Table 1: students' and teachers' opinion regarding the services to create a digitally transformed campus

Services	Respondents	1 (very satisfied)	2 (satisfied)	3 (not sure)	4 (unsatisfied)	5 (very unsatisfied)
1. Campus security	Students	57%	27%	8%	7%	1%
	Teachers	83%	17%	-	-	-
2. Information security	Students	38%	42%	9%	6%	5%
	Teachers	33%	17%	33%	17%	-
3. Student success	Students	20%	45%	29%	5%	1%
	Teachers	-	83%	17%	-	-
4. IT strategy	Students	24%	42%	22%	12%	-
	Teachers	-	67%	33%	-	-

5. Data enablement/assistance	Students	15%	37%	33%	13%	2%
	Teachers	-	50%	50%	-	-
6. Student centric services	Students	15%	32%	32%	16%	5%
	Teachers	-	50%	33%	17%	-
7. Affordability/low cost	Students	6%	25%	32%	29%	8%
	Teachers	-	-	50%	50%	-
8. Digital integration/ combination	Students	12%	43%	34%	10%	1%
	Teachers	-	83%	17%	-	-
9. Artificial intelligence	Students	10%	18%	49%	15%	8%
	Teachers	-	17%	50%	-	33%

Note: 1-very satisfied; 2-satisfied; 3-not sure; 4-unsatisfied; 5-very unsatisfied

Results in Table 2 show the combined responses in figures and percentages. The "Agree" and "Strongly agree" responses are combined and presented here as "Agreed" responses. In a similar fashion, the "Disagree" and "Strongly disagree" responses are combined and presented as "Disagreed" responses.

Table 2: combined responses of the students and teachers

SL.	Respondents	Agreed responses	Not sure	Disagreed responses
1.	Students	84%	8%	8%
	Teachers	100%	-	0%
2.	Students	80%	9%	11%
	Teachers	50%	33%	17%
3.	Students	65%	29%	6%
	Teachers	83%	17%	0%
4.	Students	66%	22%	12%
	Teachers	67%	33%	0%
5.	Students	52%	33%	15%
	Teachers	50%	50%	0%
6.	Students	47%	32%	21%
	Teachers	50%	33%	17%
7.	Students	31%	32%	37%
	Teachers	0%	50%	50%
8.	Students	55%	34%	11%
	Teachers	83%	17%	0%
9.	Students	28%	49%	23%
	Teachers	17%	50%	33%

The significant results obtained from the survey and presented in Table 1 and Table 2 demonstrate students' and teachers' beliefs about the services to create a digitally transformed campus.

The results are:
1. Like most of the students (84%), 100% of teachers ensure that their campus is secure.

2. Unlike the students (80%), 50% of teachers respond that their campus has information security. But 33% of them are not sure and 17% disagree with that.

3. While 65% of students believe that in a digitally transformed campus, they will be successful, 83% of teachers are positive about their students' success.

4. Like the students (66%), almost a similar percentage of teachers (67%) support that the campus has a comprehensive IT strategy.

5. Like the students (52%), almost a similar percentage of teachers (50%) think that they have data enablement to comprehend and connect the power of data and analytics. Therefore, 33% of respondents are not sure and 17% of them disagree whether their data enablement solutions can really help the university to meet their professional goals successfully.

6. Like the students (47%), only 50% of teachers think that the campus provides student-centric services. However, 33% of them are not sure and 17% disagree with this.

7. 37% of students disagree that their campus provides them with digital facilities at a low cost. Moreover, 32% have doubts about the affordability of digital services. Similarly, 50% of teachers disagree that their campus provides them with digital facilities at a low cost. Moreover, 50% of them doubt about the affordability of digital services.

8. It is positive that 55% of students suggest digital integration which incorporates a complex and multidimensional process with different dynamics including, the digital culture of the centre, the competency of teachers and students, the support of families and innovation within educational programs. However, 34% of them are not sure and 11% disagree with that. However, most of the teachers (83%) suggest digital integration. Nonetheless, 17% of them have doubts about it.

9. Artificial intelligence is currently being used by teachers and education administrators to analyse and interpret data by enabling them to make better-informed decisions. It helps the administrators to schedule courses and individuals to manage their daily, weekly, monthly, or yearly schedules. Therefore, personalized learning, plagiarism detection and 24/7 tutoring access are just a few ways AI enhances the classroom experience for both students and teachers. The statistics show that most (49%) of the students are not sure about the integration of AI and 23% disagree with that. Regarding AI, it is a matter of grave that most teachers either disagree (33%) or doubt (50%) about the implementation of AI. Only 17% of teachers consider that there is a provision for AI, and it is effective.

As part of the digital transformation, does your campus conforms the following nitty-gritties?
Please indicate your opinion in the following areas. Tick (√) appropriate boxes.

Table 3: students' and teachers' response regarding the institutional conformity of digital transformation

SL.	Content	Respondents	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
I.	Supports business operations, learning and research	Student	13%	45%	26%	10%	6%
		Teacher	0%	83%	0%	0%	17%
II.	Sensitive research activities are always kept secure from threats.		28%	39%	24%	5%	4%	28%
			0%	17%	67%	16%	0%	0%
III.	Use real life, real-time data to drive strategic initiatives that improve performance, roll out upgrades and make infrastructure decisions.	Student	18%	42%	32%	6%	2%
		Teacher	0%	17%	50%	33%	0%
IV.	Whether it is on-premises or in the cloud, the ultimate goal of digital transformation is to provide a single platform as the foundation of your network and communications infrastructure.	Student	17%	46%	32%	4%	1%
		Teacher	17%	17%	50%	16%	0%

Note: 1-strongly agree; 2-agree; 3-Not sure; 4-disagree; 5-strongly disagree

Table 4: combined responses of the students' and teachers' regarding the institutional conformity of digital transformation

SL.	Respondents	Agree	Not sure	Disagree
I.	Student	*58%*	26%	16%
	Teacher	*83%*	0%	17%
II.	Student	*67%*	24%	9%
	Teacher	17%	*67%*	16%
III.	Student	*60%*	32%	8%
	Teacher	17%	*50%*	*33%*
IV.	Student	*63%*	32%	5%
	Teacher	34%	*50%*	16%

From Table 4:

- o We have found both the students and teachers **conform** that the HEIs provide support for business operations, learning and research (58%, 83%).

o *Only the students comment* that the HEIs use real-life, real-time data to drive strategic initiatives (60%); and it is possible to provide a single platform through digital transformation (63%).
o On the other hand, only *the teachers* are *not sure* that, in HEIs, whether the HEIs use real-life, real-time data to drive strategic initiatives (50%); and whether it is possible to provide a single platform through digital transformation (50%).
o A considerable number of *teachers disagree* that HEIs do not use real-life, real-time data to drive strategic initiatives (33%).

Please indicate your opinion in the following areas. tick (√) appropriate boxes.

Table 5: Students' and teachers' assessment of the existing capacity of e-learning

SL.	Content	Respondents	Very satisfied	Satisfied	Not sure	Unsatisfied	Very unsatisfied
a)	How do you evaluate the technical support in on-line classes?	Students	10%	44%	23%	19%	4%
		Teachers	0%	67%	17%	16%	0%
b)	How do you appraise the curriculum/instructional design in your present digital learning?	Students	12%	51%	26%	7%	4%
		Teachers	0%	67%	17%	16%	0%
c)	How much has your institution modernized the infrastructure capacity for digital learning?	Students	20%	52%	17%	7%	4%
		Teachers	0%	100%	0%	0%	0%
d)	The present curriculum/instructional design is development standards as well as platform standards for digital learning.	Students	16%	42%	34%	7%	1%
		Teachers	0%	67%	0%	33%	0%
e)	Teachers are highly qualified personnel to conduct on-line classes.	Students	24%	44%	23%	8%	1%
		Teachers	0%	33%	17%	50%	0%
f)	Digital learning can ensure the quality of education.	Students	17%	32%	35%	8%	8%
		Teachers	0%	33%	17%	50%	0%
g)	"My exam performance with the e-proctoring system was better than the one I would obtain in the face-to-face assessment".	Students	20%	30%	18%	16%	16%
		Teachers	0%	0%	50%	33%	17%
h)	"The e-proctoring system use in the test positively impacted concentration, attention, time management, anxiety, understanding, and motivation during the exam".	Students	17%	28%	32%	12%	11%
		Teachers	0%	17%	33%	33%	17%

Note: 1-very satisfied; 2-satisfied; 3-not sure; 4-unsatisfied; 5-very unsatisfied

From Table 5, let us combine the 'satisfied' and 'unsatisfied' responses. It appears as below:

Table 6: combined responses of the students' and teachers' on assessment of existing capacity of e-learning

SL.	Content	Respondents	Satisfied	Not sure	Unsatisfied
a)	How do you evaluate the technical support in on-line classes?	Students	54%	23%	23%
		Teachers	67%	17%	16%
b)	How do you appraise the curriculum/instructional design in your present digital learning?	Students	63%	26%	11%
		Teachers	67%	17%	16%
c)	How much has your institution modernized the infrastructure capacity for digital learning?	Students	72%	17%	11%
		Teachers	100%	0%	0%
d)	The present curriculum/instructional design is development standards as well as platform standards for digital learning.	Students	58%	34%	8%
		Teachers	67%	0%	33%
e)	Teachers are highly qualified personnel to conduct on-line classes.	Students	68%	23%	9%
		Teachers	33%	17%	50%
f)	Digital learning can ensure the quality of education.	Students	49%	35%	16%
		Teachers	33%	17%	50%
g)	"My exam performance with the e-proctoring system was better than the one I would obtain in the face-to-face assessment".	Students	50%	18%	32%
		Teachers	0%	50%	50%
h)	"The e-proctoring system use in the test positively impacted concentration, attention, time management, anxiety, understanding, and motivation during the exam".	Students	45%	32%	33%
		Teachers	17%	33%	50%

From the Table 6:

- o We have found that both students and teachers are *satisfied* with the existing capacity of e-learning to the extent of technical support in online classes (54%, 67%); curriculum/instructional design of the present digital learning (63%, 67%); modernized infrastructure capacity for digital learning (72%, 100%); present curriculum development standards as well as platform standards for digital learning (58%, 67%).
- o 68% of the students consider that their teachers are highly qualified personnel to conduct online classes. 49% of them think that digital learning can ensure the quality of education. 50% of students commented that their exam performance with the e-proctoring system was better than face-to-face assessment and 45% stated that the e-proctoring system used in the test positively impacted concentration, attention, time management, anxiety, understanding, and motivation during the exam.
- o The teachers give interesting data. While the students consider that their teachers are enough qualified to conduct online classes, 50% of teachers themselves admit that they are not enough qualified to conduct online classes and 17% of them are not sure about that. Similarly, while half of the students suggest that digital learning can

ensure the quality of education, 50% of teachers disagree with that and 17% are not sure.

o   The teachers are also highly dissatisfied with the e-proctoring system. 50% of them are dissatisfied and 50% are not sure whether their students' exam performance with the e-proctoring system is better than the face-to-face assessment. This is supported by half of the students as 32% of them are not satisfied with the e-proctoring system and 18% are not sure. Both teachers and students further ensure this. While 50% of teachers disagree that the e-proctoring system used in the test did not positively impact concentration, attention, time management, anxiety, understanding, and motivation during the exam, 33% of them are not sure about the e-proctoring system. Similarly, 33% of students are dissatisfied and 32% of them are not sure.

Interview Data
Major impediments to digital transformation at the tertiary level of education in Bangladesh

When asked about what are the impediments to digital transformation at the tertiary level of education in Bangladesh, all of the interview respondents expressed that they have a positive attitude towards digital transformation of higher educational institutions in Bangladesh. However, some limitations need to be overcome. In response, Teacher 2 revealed the following information:

We do not have any policy or legislative frameworks to conduct online classes. Moreover, we are not trained. Our internet network is poor.

Another teacher (Teacher 6) focused on the following issues as major impediments to implementing digital transformation at the tertiary level.

Though we have technical staff, there is a scarcity of specialist technical staff to support e-learning. Our present data enablement solutions are very limited and Artificial Intelligence is not fully functional. Moreover, our data are vulnerable to cyber threats.

8 of the interview respondents emphasised that there are major challenges for implementing digital transformation at the tertiary level in Bangladesh. They claim that e-learning contexts do not provide an input-rich environment for the learners.

Major steps that can be taken for digital transformation at tertiary level of education in Bangladesh

Some of the interview respondents highlighted that there is a need to modernize the present curriculum to meet the new ways of digital learning. Some mentioned that we need a highly skilled workforce with technological skills. Teacher 4 said-

Since DT urges a practical and creative education, incorporating new digital cooperative learning, virtual reality, gamification and so on, both teachers and students need training.

One (Teacher 8) of the teachers mentioned 'digital maturity'. Teacher 8 proposed that-

The university does not need to have the solutions to all digital problems, but the people within the university must have the skills and the tools to find those answers quickly and act upon the business needs of the organization rather than just talk about the digital needs

Findings
Students' and teachers' assessment of existing capacity of e-learning

o   We have found that both students and teachers are *satisfied* with the existing capacity of e-learning to the extent of technical support in online classes; curriculum/instructional design of the present digital learning; modernized infrastructure capacity for digital learning; present curriculum development standards as well as platform standards for digital learning.

o   Half of the students consider that their teachers are highly qualified personnel to conduct online classes; digital learning can ensure the quality of education; their exam performance with the e-proctoring system was better than face-to-face assessment; and e-proctoring system use in the test positively impacted concentration, attention, time management, anxiety, understanding, and motivation during the exam. But from the rest half, we got a negative response.

o   The teachers give interesting data. While the students consider that their teachers are enough qualified to conduct online classes, half of them admit that they are not enough qualified to conduct online classes and some of them are not sure about that. Similarly, while half of the students suggest that digital learning can ensure the quality of education, the teachers disagree with that.

o   Half of the respondents (both teachers and students) are highly dissatisfied with the e-proctoring system.

Capacity of the HEIs for digitalization

o   The result shows that the HEIs are providing training/workshops to their teachers and students which is a positive sign for the digital transformation of the HEIs.

o   The statistics reflect that during the pandemic the online policy has developed which is workable but not well planned. According to this result, it is implied that most of the HEIs in Bangladesh have developed institutional policy and legislative frameworks, rules, and norms to conduct online classes during the pandemic which needs improvement and good planning.

o   According to the study, most of the teachers and students report that the support structure is very small.

o   On the issue of technical staff to support e-learning, most of the students and teachers respond that their institutions have fairly enough technical staff to support e-learning; though some of them consider it moderate; while some others think it is not adequate.

o   Almost all the teachers and students admit that they received both formal and informal incentives from the institution for conducting online classes. However, one-third of them stated that they did not receive any incentive.

o   Most of the students responded that their technological skills for conducting online classes are satisfactory though some of them admitted that they are not technologically sound.

o   The students responded that their teachers' technological skills for conducting online classes are good, while the teachers consider that their technological skills are fair. Therefore, there is a similarity between students' assessments and teachers' claims. The fact is that teachers as 'digital emigrants' are equipping themselves with technolog,y which is very positive for digital transformation.

o   We have found half of the respondents commented that they have adequate technological devices to support online teaching/learning. However, a good number of teachers and students claim that they have workable technological devices to take online classes and some of them have inadequate support. The result shows that though the teachers and students have technological support still it is not up to the standard for digital transformation.

o   The study shows a maximum number of students and teachers have a good internet connection, while a considerable number of them report that the internet connection is poor. Only a few students are having excellent uninterrupted internet connections. The fact is, neither of the respondents are giving an opinion about uninterrupted internet connection which is necessary for digital transformation.

o The study result shows that while a maximum number of students comment that their institutions do not have a digital academic library, most of the teachers comment that their institutions have a digital academic library. It shows that either the students are not aware of the digital library facility, or they do not use library resources. However, if the situation is like that, then it is definitely a barrier to digital transformation.

Students and teachers' beliefs about the services to create a digitally transformed campus

o Almost all respondents agree that their campus is secure.
o Though most of the students agree that they have campus network security, the teachers partially agree with that. The teachers think the present condition of digital campus network information security is not totally out of a threat to it.
o Most of the students and teachers believe that their institutions are offering them increased and more equitable access to digital learning resources which benefit them and provide a more engaging university experience.
o Most of the students and teachers comment that their campus has a comprehensive IT strategy.
o Regarding data enablement, we got a mixed response from the respondents. Half of the students and teachers think that they have data enablement to understand and harness the power of data and analytics. But the rest are either not sure or disagree whether their data enablement solutions and strategies can help the university quickly, so that they can successfully meet their professional goals.
o Most of the students and teachers comment that their campus does not provide them with digital facilities at low cost. Moreover, one-third of them have doubt about the affordability of digital services.
o It is encouraging that most of the students and teachers suggest digital integration which incorporates a complex and multidimensional process with different dynamics including, the digital culture of the center, the competency of teachers and students, the support of families and innovation within educational programs.
o Artificial intelligence (AI) is currently being used by teachers, students and other education stakeholders to analyze and interpret data by enabling them to make better-informed decisions. It helps the administrators to schedule courses and individuals to manage their daily, weekly, monthly, or yearly schedules. Therefore, personalized learning, plagiarism detection and 24/7 tutoring access are just a few ways AI enhances the classroom experience for both students and

teachers. However, the study results show that most of the students and teachers are not sure about the integration of AI and some of them disagree with that.
o We have found that both the students and teachers conform that the HEIs support business operations, learning and research.

Students' and teachers' response regarding the institutional conformity of digital transformation
o ***Both*** respondents were ***not sure*** whether the HEIs are vulnerable to cyber threats; whether the data enablement is possible or not; and whether the "Freemium" software and on-demand services are cheaper.
o ***Only the students reported*** that, in HEIs, sensitive research activities are always kept secure from threats; data enablement can be extremely challenging to protect; communications network is of high capacity, secure and smart; the HEIs use real-life, real-time data to drive strategic initiatives; and it is possible to provide a single platform through digital transformation.
o On the other hand, only ***the teachers*** disagreed or were ***not sure*** about, in HEIs, whether the sensitive research activities are always kept secure from threats; whether the communications network is of high capacity, secure and smart; whether the HEIs use real-life, real-time data to drive strategic initiatives; and whether it is possible to provide a single platform through digital transformation.

Major challenges for digital transformation
From the above discussion, we have found the following challenges for digital transformation in HEIs in Bangladesh, which need to be addressed:
o Most of the HEIs in Bangladesh have no policy and legislative frameworks, rules, and norms to conduct online classes.
o There are clear differences in technology use between teachers and students. It reflects the difference between the 'digital natives' and 'digital immigrants' (Prensky, 2001). Therefore, the digital literacy of all stakeholders is an important challenge.
o One of the major impediments to the successful implementation of online teaching and learning is poor internet networks. It hinders the proper delivery and understanding of lessons. Lack of interaction and motivation are also caused due to poor internet networks. It also affects students' performance. The fact is, HEIs in Bangladesh do not have uninterrupted internet connection which is necessary for digital transformation.

- o The existing format of pedagogy, curriculum and syllabus is not completely functional or outcome-based for digital platforms of teaching and learning.
- o The present condition of digital campus network information security is not totally out of threat.
- o For digital transformation, a challenge is related to the financial constraints of HEIs. As emerging technologies are often expensive, they cause financial constraints for DT. Access to these technologies is not open and their maturity level is still not ideal. Thus, it creates a financial burden on the students and teachers.
- o The technological support is not up to the standard for digital transformation.
- o Most of the institutions have less or no support structures, equipment, and finances.
- o Though the HEIs have technical staff, there is a challenge for specialist technical staff to support e-learning.
- o The present data-enabling solutions and strategies are very limited.
- o The integration of Artificial Intelligence is not fully functional.
- o HEIs are vulnerable to cyber threats. The communications network is not of high capacity, secure and smart.
- o Most of the HEIs in Bangladesh do not have a digital academic library.
- o All teachers are qualified enough to conduct online classes.
- o Creates a disparity in the degree of learning or knowledge comprehension within the students as all students in developing countries like Bangladesh, do not have the same access to internet facilities.
- o There is a lack of workshops/training being arranged on online learning by the HEIs.
- o The sensitive research activities are not always kept secure from threats.
- o The e-proctoring system is not effectively functional due to poor internet connection and unfamiliarity with the digital gateway.

Recommendations

Only institutional conviction of the need to exploit the boost of the digital revolution and the solid commitment of students, professors, researchers, staff and managers will allow the university to be successful in the digital era. This process entails the digital infrastructure growth, the development of the academic staff's skills to use digital methods in their teaching and the improvement of its students' digital skills, as well as other significant challenges among which we emphasized the knowledge leadership and pedagogical and curricula changes. Thus, digital transformation is now

imperative to develop a new educational paradigm (Saykili, 2019). For the digital transformation of the HEIs in Bangladesh, the present research would like to proposes the following recommendations, which have already been explored in many aspects in different contexts in other countries:

- Whatever the digital transformation strategy adopted, HEIs must have a strategic vision for digital transformation. Higher education institutions should set up their strategies with clear and specific goals for their DT. To do so, it is important to have strong leadership and a specialized team that can confidently explain and implement their plans. A clear vision will make the team and stakeholders more involved and invested in the process of digital transformation (Rodrigues, 2017).
- According to Rodrigues (2017), generally, the young generations have more digital skills than older generations. The success of a digital strategy is strongly dependent on the ability of these different stakeholders to adapt to the emerging technologies and to make efficient use of them.
- There is a need to modernize the curriculum to meet current educational standards and techniques, including discovering new ways to accelerate digital learning and expanding the use of information and communication technologies (Bozhko, Maksimkin, Baryshev, Voronin, & Kondratyeva, 2016).
- In the present digital era, a new highly skilled workforce with technological skills and expertise in technology and contemporary knowledge is required.
- DT drives a practical and creative education, incorporating new didactic models for students to learn and teachers to teach, such as Digital Cooperative Learning, Virtual Reality, Gamification and so on (Abad et al., 2020). Betting on creativity and entrepreneurship, the DT applied in education advocates establishing learning methods based on individualized training, personalization of content, and the development of one's own skills, through social learning (Jahnke & Kumar, 2014).
- Training may be provided to teachers and students for online teaching and learning.
- It is essential to ensure a 4G/5G network nationwide.
- The Learning Management System (LMS) can be a significant help to both teachers and students. Thus, the advantages compensate for the disadvantages by far.
- Financial aid and mobile balance for underprivileged students can facilitate the students to bring them an online platform.

Laptops/Tablets/Smart mobile phones may be provided to the students either free of cost or based on interest-free loans.

Digital maturity model

Instead of digital transformation, we can adopt 'digital maturity'. Brown (2018, p. 12) suggests that "digital maturity doesn't necessarily mean the organization will have all the answers to all digital things, but it does mean that the people within the organization will have the skills and the tools to find those answers quickly and act upon the business needs of the organization rather than just talk about the digital needs". Thus, reaching digital maturity is an ongoing process that unfolds around the organization over time. No organization can become digitally mature overnight. There are many frameworks for measuring digital maturity in other industries (e.g., Iyengar et al., 2021; Kane et al., 2017), but very few for HEIs (Doneva et al., 2019; Duarte & Martins, 2011; Durek et al., 2017; Molina-Carmona et al., 2019; South Australian Government, 2015).

According to Alenezi (2021), the digital maturity (DM) of an HEI will grow by adding the implementation of: a) digitalization initiatives (DI) to optimize a business operation to achieve a specific benefit, mainly related to cost reduction, or to make processes faster and more efficient; b) IT governance best practices (ITGI), whose goal is to support better strategic decision-making about IT; and c) digital transformation initiatives (DTIs), which are business-driven initiatives whose purpose is to create new business processes that require overall strategic organizational change, using the latest digital technologies, and adding high value to all stakeholders.

If HEIs want to increase their digital maturity, they should work in all these areas, but if they want to accelerate their digital maturity, they should invest their efforts in DTIs. Thus, according to Gurumurthy and Schatsky (2019, p. 11), "an organization's digital maturity correlates with the scope of its digital transformation efforts" and "organizations that are more digitally mature are deriving greater benefit from digital transformation efforts […]. In other words, the more comprehensive and coordinated an organization's digital transformation efforts are, the more likely it is to be digitally mature".

There are different frameworks and models for the digital transformation of higher education institutions proposed by three leading firms: KPMG, Google, and Microsoft. It is also found that with such a high need for digital transformation, higher education institutes have been lagging behind other industries and business organizations due to several challenges. Therefore, in Bangladesh, our HEIs can adopt "digital maturity" models for the greater benefit of digital transformation efforts.

Conclusion

The digital transformation is relevant to various aspects of the higher education system, including teaching, pedagogy, learning, curriculum design, infrastructure, and administrative management. To meet their organizational goals, any entity looking to modernize must develop a digital strategy, and higher education institutions (HEIs) are no different. In the wake of the pandemic, HEIs are required to embrace new and innovative digital experiences for their stakeholders. Therefore, it's crucial for these institutions to adopt a holistic approach to digital transformation, integrating it through a comprehensive framework. This framework should incorporate "digital maturity" models to ensure that all elements of the digital strategy are cohesively managed.

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Awareness of Climate Change and Adaptation Strategies Among Secondary School Students in Ogbaru Local Government Area of Anambra State, Nigeria

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Abstract

This study investigated the awareness of climate change and adaptation strategies among secondary school students in Ogbaru Local Government Area of Anambra State, Nigeria. Two research questions guided, and two null hypotheses were tested at the 0.05 level of significance. The researchers employed a descriptive survey research design. The population consisted of 8,564 JSS and SS students from the 9 public secondary schools in the area. The sample size consisted of 170 students from the four schools sampled for the study using a simple random sampling technique (balloting). Data was collected using the 40-item climate change awareness and adaptation strategies questionnaire (CCASSQ) developed by the researchers and validated by experts. An estimate of the stability of the instrument yielded a

reliability coefficient of 0.88 using Cronbach's Alpha statistic. Mean and standard deviation were used as descriptive statistics, while the independent samples t-test was adopted as an inferential statistic. The findings revealed a high level of awareness of climate change by the JSS and SS students. It also indicated a high level of awareness of climate change adaptation strategies by JSS and SS students in Ogbaru LGA of Anambra State. Based on the findings, it was recommended that the government should strengthen educational infrastructure, such as wind vanes and rain gauges, that could enable the teachers to meet the demands of this era of climate change.

Keywords: Adaptation, Awareness, Climate change, Junior Secondary, Senior secondary, Strategies

Introduction

One of the fundamental issues facing the world today is climate change. It is one of the most complex challenges of the 21st century. This is informed by the impact of the ever-growing complexities in the world's technological advancement, witnessed as centuries pass by. According to Onyali, Ezeugbor and Okoye (2015), climate change is caused by humans and nature. Amanchukwu, Amadi-Ali and Ololube (2015) stated that human activities such as the burning of fossil fuels, carbon emissions, and deforestation, among others, have negatively impacted the climate, resulting in changes in climate patterns. Climate change has been given several definitions. Moreno and Perdomo (2018), for instance, define climate change as a stable and durable change in the distribution of climate patterns over a period of time ranging from decades to millions of years. Mitchell, Williams, Hudson & Johnson (2017) define climate change as any change in climate, whether it is due to natural variability or as a result of human activity. Udegbunam and Onyegegbu (2021) refer to climate change as a fundamental element of the environment that causes alteration in an ecosystem if its variation becomes erratic. Eze, Sampson, Okoro and Okafor (2024) define climate change as a change of climate attributed directly or indirectly to human activities in the physical environment that alter the composition of the atmosphere, which is in addition to natural variability recorded for a long period of time. Even as the list of definitions of climate change may not be exhaustive, what is clear is the fact that the change in the climate might occur naturally or might be influenced by human activities.

Climate change is an issue that is generating widespread apprehension and is taking centre stage in virtually every human endeavour in the world today (Bristow & Ford, 2016). This phenomenon has been observed to have serious deleterious consequences for the Earth in the form of significant variations in regional climates, recurrent droughts, excessive heat waves,

windstorms, killer floods, and so on. It is one of the greatest public policy issues of our time. In Nigeria, for instance, noticeable consequences of climate change could be seen in some areas, such as intense thunderstorms, widespread floods, and incessant droughts, among others. In Nigeria, the trends of climate hazards such as erosion, pollution, floods, changes in precipitation, gas emissions, and diseases have brought a lot of hardship to the country. Ogbaru Local Government Area of Anambra State is not exceptional in these effects of climate change. These changes in weather patterns have brought in their wake devastating impacts in this area. This is further elucidated by Pinga (2018) that global warming, influenced by changes in climate patterns, is evident in temperature variations, the drying up of soils and water bodies, increased pests and diseases, shifts in suitable areas for growing crops and livestock, increased desertification in the Sahara region, and change in rainfall patterns, which lead to erosion and flooding of farmlands, homes, and schools.

Consequently, Nigeria, in keeping with the dynamics of social change and the demands on education, revised its school curricula to include climate change awareness at all levels of secondary education. Awareness of climate change could help students and other individuals become scientifically and ecologically literate citizens who can describe, explain, and predict natural phenomena using sound ecological thinking and are capable of full participation in a democratic, sustainable society. The level of awareness of the impact of climate change could lead people to engage in activities that reduce the problems posed by the phenomenon. Chinedu (2018) viewed awareness as a state of consciousness and understanding of one's surroundings. Awareness is the state or ability to perceive, to feel, or to be conscious of events, objects, or sensory patterns. It means having an idea of the existence of something. In relation to the above views, Turbuck and Lutgens (2018) equate awareness with knowledge of, understanding of, appreciation of, recognition of, attention to, perception of, consciousness of, acquaintance with, enlightenment with, mindfulness of, and cognizance of something. Climate change awareness also involves creating knowledge, understanding and values, attitudes, skills, and abilities among individuals and social groups towards the issues of climate change for attaining a better-quality environment.

The majority of Nigerians, including people of Ogbaru Local Government Area of Anambra State, seem to be unaware of climate change and the likely challenges despite the havoc caused in the area yearly. The Nigerian government, in creating awareness, put measures in place to mitigate the impacts of climate change. Ochieng (2014) argued that even as resources were put together to mitigate climate change, there was a need to educate people on what the phenomenon really is. Increasing people's awareness of

climate change through education is an important measure to persuade people at all levels in the community to play an active role in mitigating and adapting to it. It is a known fact that awareness and enlightenment of people/communities on issues related to climate change and its effects on humans and their environment could definitely be the right instrument in combating its challenges in Nigeria in particular and the world in general.

Climate specialists have reportedly pointed out that a solution to climate change problems will require awareness and effective strategies to assist the vulnerable to cope with and reduce the effects of the negative impacts. In the context of this study, though in relation to the above views, awareness implies understanding and knowledge of the activities and events (like climate change) going on around one's environment. This knowledge and understanding, to a large extent, could perhaps determine the adaptation strategies taken by these individuals against the effects of climate change. Global warming is one of the greatest threats facing humankind today and needs urgent action to address the impacts. One such action is adaptation action, which could be used to reduce the adverse effects of climate change.

Adaptation means to become used to something. It is the ability to change something to make it more suitable. It is the process of adjusting to new conditions, stresses, and natural hazards that result from climate change (Schiper, 2012). Further, Schipper emphasized that adaptation to climate change takes place in response to experienced impacts as well as in anticipation of expected impacts. Adaptation in the context of climate change therefore, aims to reduce the vulnerability and improve the coping capacity or resilience of the people who rely on climate resources for their livelihood. In the same way, adaptation in the context of climate change includes policies and measures to reduce exposure to climate variability and extremes and the strengthening of adaptive capacity. Numerous studies conducted revealed that climate change responses cannot be effective unless the different needs of men and women are considered, particularly the boys and girls with limited or no access to community resources (Babugura, 2015; Bryan, Alvia, Huyer & Ringler, 2024). Adaptation is one of the responses to climate change in developing countries like Nigeria.

Adaptation seeks to lower the risk posed by the consequences of climate change. It is a practical step to protect countries and communities from likely disruption and damage that will result from the effects of climate change. Proper adaptation measures could help to minimize the adverse effects or to take advantage of any beneficial effects of climate change. Adapting to the changes has consequently emerged as a solution to address the impacts of climate change that are already evident in some regions (Ogali, 2012). This is because awareness and quality of knowledge on existence and issues relating to climate change adaptation could reduce the impact of the phenomenon. Eze

et al. (2024) explained that climate change adaptation includes policies and measures to reduce exposure to climate variability and extremes and the strengthening of adaptive capacity. It involves managing new risks and strengthening resilience in the face of change.

Climate change adaptation is an area that is in dire need of publicity to help the public make informed decisions in its adaptation and mitigation. The level of awareness and attitude of learners about climate change, therefore, needs to reflect that complexity and be multidimensional and multifaceted, rather than focusing only on single variables such as carbon dioxide emissions. Above all, awareness and attitude towards climate change adaptation are the practical enlightenment that can help learners deal with uncertainty whenever the menaces of climate change occur. To ensure adequate adaptation and mitigation of the harmful impacts of climate change on our society, there is a need for adequate knowledge of the phenomenon.

Statement of the Problem

In Anambra State, it appears that many people, particularly in Ogbaru Local Government Area, are not aware of the causes and effects of climate change. The state is witnessing cases of flooding, late onset and early cessation of rains, increasing temperature, and incidence of malaria, among others, all of which affect lives and livelihoods. Flooding is devastating many communities, schools, and institutions in the state, especially in Ogbaru Local Government Area. In fact, some villages in the area have had substantial parts of their communities destroyed by the flood menace; thus, the people are forced to live as refugees in other parts of the state during the rainy season. Schools, churches, and other institutions are forced to close during this period every year.

The seeming ignorance of many people in Anambra State at large and Ogbaru Local Government Area in particular makes them sometimes engage in activities that contribute to the problems of climate change. This leaves one in doubt about the level of awareness of the causes and the effects of climate change and adaptation strategies put in the education system to facilitate control against the phenomenon. Considering this scenario, one wonders why emphasis on climate change awareness and adaptation strategies for its control have not been accorded much importance in secondary schools in Anambra State, Ogbaru Local Government Area, inclusive. Climate change as a topic features only in the secondary school geography syllabus. Considering the fact that only a few students offer this subject in secondary schools, it is possible that the majority of the students may not know what climate change is all about, its causes, and effects; hence the need for this study, which investigated the awareness of climate change and adaptation strategies among secondary school students in Ogbaru Local Government Area of Anambra State, Nigeria.

Purpose of the Study

The general purpose of the study is to investigate the awareness of climate change and adaptation strategies among secondary school students in Ogbaru Local Government Area of Anambra State, Nigeria. Specifically, the study aimed to determine the:

1. students' level of awareness of climate change.
2. students' level of awareness of climate change adaptation strategies.

Research questions

The following research questions guided the study:

1. What are the mean responses of JS and SS students on their level of awareness of climate change?
2. What are the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies?

Hypotheses

o **HO$_1$:** There is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change.

o **HO$_2$:** There is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies.

Method

The study employed a descriptive survey research design. Two research questions and two null hypotheses guided the study, which was carried out in Ogbaru Local Government Area of Anambra State, Nigeria. The population of the study consisted of 8,564 junior secondary school (JSS) and senior secondary school (SS) students in 9 public secondary schools in the area (Post Primary Schools Service Commission [PPSSC], 2024). The junior secondary schools (JSS) have a population of 4,720 students, and the senior secondary schools (SS) have a population of 3,844 students. The sample consisted of 170 JSS and SS students in Ogbaru Local Government Area. The study adopted a multi-stage sampling procedure in the selection of the sample size and the schools used for the study. In the first stage, four (4) schools out of the nine (9) schools in the area were selected using a purposive sampling technique, considering urban and rural schools. In the second stage, sampling at the participants' level (students) was done, first by determining two percent of JS and SS students, which gave a total of 170 for both JS and SS students. Finally, to ensure greater representation of the sample relative to the population and guarantee that minority constituents of the population are represented in the sample, a proportionate stratified sampling technique was

used to draw 94 JSS and 76 SS students, making a total of 170 students from 4 secondary schools in Ogbaru Local Government Area.

The instrument used for this study was the 40-item climate change awareness and adaptation strategies questionnaire (CCASSQ) developed by the researchers and validated by experts. The instrument had two clusters to elicit information based on the two research questions. Cluster A assessed the level of awareness of students on climate change. Cluster B elicited information on the adaptation strategies towards climate change effects. All clusters were structured under a four-point scale of Very High Level (4), High Level (3), Low Level (2), Very Low Level (1), from which students would tick ($\sqrt{}$) in the blank spaces that represent their stance towards each item in the scale. Cronbach's Alpha procedure was used to find the internal consistency of the items for scores derived from the trial testing. An overall internal consistency reliability estimate of 0.88 was obtained, which indicated that the instrument was reliable. The researcher, with the aid of research assistants, administered the instrument. The data generated was analyzed with descriptive statistical tools. Mean and standard deviation were used to answer the research questions. The real limit decision points of 0.00 – 1.49 (Very Low Level), 1.50 – 2.49 (Low Level), 2.50 – 3.49 (High Level), 3.50 – 4.00 (Very High Level) were used for taking decision while independent samples t-test statistics were used to test the null hypotheses at 0.05 level of significance.

Results

Research Question 1: What are the mean responses of JS and SS students on their level of awareness of climate change?

Table 1: Mean and Standard Deviation of the Respondents on Their Level of Awareness of Climate Change

S/N	Item Statement: I am aware that	Group	n	M	SD	Decision
1.	Climate change means an increase in temperature and changes in weather patterns created by carbon and other greenhouse gas emissions.	JS	94	2.88	.65	HL
		SS	76	3.21	.64	HL
2.	Climate change is caused by persistent afforestation.	JS	94	2.36	.55	LL
		SS	76	2.78	.42	HL
3.	Climate change is caused by persistent deforestation	JS	94	2.22	.51	LL
		SS	76	2.04	.58	LL
4.	Bush burning contributes to the warming of the atmosphere.	JS	94	2.68	.47	HL
		SS	76	3.50	.53	VHL
5.	Climate change is a result of climate forces and natural factors.	JS	94	2.53	.50	HL
		SS	76	3.50	.50	VHL
6.	Human activities are the main cause of climate change.	JS	94	2.55	.56	HL
		SS	76	2.47	.50	LL
7.	Carbon emission from the burning of fossil fuels is primarily responsible for climate change.	JS	94	3.20	.40	HL
		SS	76	3.24	.56	HL

8.	Climate change is caused by carbon monoxide from industrial plants and vehicles.	JS	94	3.21	.53	HL
		SS	76	3.21	.60	HL
9.	Climate change is the divine punishment meted out on the world for numerous sins that the world has committed against the environment and God who created it.	JS	94	2.77	.97	HL
		SS	76	2.74	1.06	HL
10.	Vegetation and soils at the land surface control how energy received from the sun is returned to the atmosphere.	JS	94	2.84	1.01	HL
		SS	76	2.84	.92	HL
11.	Urbanization affects the global surface temperature.	JS	94	3.18	.77	HL
		SS	76	2.96	.90	HL
12.	The use of generators to provide electricity produces carbon that increases temperature.	JS	94	2.86	.82	HL
		SS	76	3.08	.73	HL
13.	Climate change will result in higher-intensity rainfall with changing precipitation patterns.	JS	94	3.01	.75	HL
		SS	76	2.83	.82	HL
14.	Climate change leads to overflooding of low-lying areas and destruction of lives and properties.	JS	94	3.07	.81	HL
		SS	76	3.03	.80	HL
15.	Climate change causes lung problems/diseases.	JS	94	2.47	.94	LL
		SS	76	2.50	.99	HL
16.	Gully erosion results from climate change.	JS	94	3.30	.70	HL
		SS	76	3.16	.85	HL
17.	Climate change leads to sea level rise.	JS	94	2.71	.95	HL
		SS	76	2.62	.97	HL
18.	Climate change leads to severe heat burns.	JS	94	2.12	.89	LL
		SS	76	2.03	.97	LL
19.	Climate change leads to excessive windstorms.	JS	94	2.39	.91	LL
		SS	76	2.30	.82	LL
20.	Climate change leads to poverty through its activities.	JS	94	2.89	.90	HL
		SS	76	2.83	.84	HL
	Cluster Mean	**JS**	**94**	**2.76**	**.24**	**HL**
		SS	**76**	**2.84**	**.27**	**HL**

Key: Real Limit Decision Points: VHL = Very High Level (3.50 – 4.00), HL = High Level (2.50 – 3.49), LL = Low Level (1.50 – 2.49), VLL = Very Low Level (0.50 – 1.49), n = Sample size, M = Mean, SD = Standard Deviation.

Table 1 shows the mean responses of JS and SS students on their level of awareness of climate change in Ogbaru LGA of Anambra State. It indicates that the mean responses of the JS and SS students to items 1, 7 – 14, 16, 17 and 20 are in the real limit decision point of 2.50 – 3.49. This implies that the JS and SS students in the secondary schools are aware of the statements in items on a high level. Also, the mean responses of JS and SS students to items 3, 18 and 19 are in the real limit decision point of 1.50 – 2.49. This implies

that the JS and SS students are aware of the statements in the items on a low level. Further still, the table shows that the mean responses of JS students to items 2 and 15 are in the real limit decision point of 1.50 – 2.49, while those of their SS student counterparts are in the real limit decision point of 2.50 – 3.49. The implication of this is that the JS students are aware of the statements in the items on a low level, while their counterparts in the SS class are aware of the statements in the items on a high level. The table finally indicates that the mean responses of JS students to items 4 and 5 are in the real limit decision point of 2.50 – 3.49, while those of their SS student counterparts are in the real limit decision point of 3.50 – 4.00. It implies that the JS students are aware of the statements in the items on a high level, while their counterparts in SS class are aware of the statements in the items on a very high level. The cluster means (M = 2.76, SD = .24) and (M = 2.84, SD = .27) for the JS and SS students, respectively, imply that the JS and SS students indicated a high level of awareness of climate change in Ogbaru LGA of Anambra State, though the SS students obtained a higher mean score than the JS students.

Hypothesis 1: There is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change.

Table 2: t-test scores on JS and SS students' level of awareness of climate change in Ogbaru LGA

Group	n	X	SD	Df	t-cal	Sig. (2-tailed)	Decision
JS	94	2.76	.24				
				168	-2.01	.046	HO_1 Not Accepted
SS	76	2.84	.27				

Data in table 2 shows the t-test score on the level of awareness of climate change, $t(168) = -2.01$, $p = .046 < .05$. Since the p-value of .046 is less than the 0.05 probability level set for the study, the null hypothesis, which states that there is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change, is not accepted. This implies that there is a significant difference in the mean responses of JS and SS students on their level of awareness of climate change in Ogbaru LGA of Anambra State in favour of the SS students.

Research Question 2: What are the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies?

Table 3: Mean and Standard Deviation of the Respondents on Their Level of Awareness of Climate Change Adaptation Strategies

S/N	Item Statement: I am aware of the following climate change adaptation strategies:	Group	n	M	SD	Decision
21.	Strengthening early warning signs.	JSS	94	3.07	.82	HL
		SS	76	2.63	.91	HL
22.	Switching to early-maturing varieties of crops.	JSS	94	2.47	.98	LL
		SS	76	2.67	.97	HL
23.	Tree planting and reforestation.	JSS	94	2.64	1.06	HL
		SS	76	2.67	1.02	HL
24.	Reduce raw material usage like wood.	JSS	94	3.20	.86	HL
		SS	76	3.18	.76	HL
25.	Encourage recycling of waste materials.	JSS	94	3.37	.84	HL
		SS	76	3.34	.83	HL
26.	Planting trees that thrive on erosion lands, such as bamboo tree.	JSS	94	2.01	.80	LL
		SS	76	2.03	.83	LL
27.	Decrease the use of old cars.	JSS	94	2.72	.99	HL
		SS	76	2.72	1.03	HL
28.	Proper disposal of waste in the environment.	JSS	94	1.99	1.06	LL
		SS	76	2.05	1.06	LL
29.	Increased use of solar energy.	JSS	94	2.72	.90	HL
		SS	76	2.84	.90	HL
30.	Mounting awareness campaigns through the radio and television.	JSS	94	2.01	.95	LL
		SS	76	2.04	.97	LL
31.	Listening to information about climate change.	JSS	94	2.82	.80	HL
		SS	76	2.83	.77	HL
32.	Resettlement of flood victims to avoid future occurrences.	JSS	94	2.65	.97	HL
		SS	76	2.86	1.00	HL
33.	Ensure that drains are cleared regularly.	JSS	94	2.88	.93	HL
		SS	76	2.88	.89	HL
34.	Construction of embankments to keep water back against pollution of the wetland.	JSS	94	2.39	.96	LL
		SS	76	2.55	.97	HL
35.	Construct fish ponds in the flooded area.	JSS	94	3.12	.83	HL
		SS	76	3.17	.81	HL
36.	Switch to other crops that can tolerate floods and heavy rainfall.	JSS	94	2.96	.80	HL
		SS	76	3.07	.75	HL
37.	Provision of relief materials from good-spirited individuals and the government.	JSS	94	2.97	1.04	HL
		SS	76	3.05	.95	HL
38.	Free medicine from the government to flood victims.	JSS	94	2.89	.91	HL
		SS	76	3.01	.90	HL
39.	Helping people in evacuation centers.	JSS	94	3.16	.83	HL
		SS	76	3.08	.89	HL
40.	Fumigation of all flooded areas.	JSS	94	2.94	.85	HL
		SS	76	3.07	.85	HL
	Cluster Mean	**JSS**	**94**	**2.75**	**.31**	**HL**
		SS	**76**	**2.79**	**.32**	**HL**

Key: Real Limit Decision Points: VHL = Very High Level (3.50 – 4.00), HL = High Level (2.50 – 3.49), LL = Low Level (1.50 – 2.49), VLL = Very Low Level (0.50 – 1.49), n = Sample size, M = Mean, SD = Standard Deviation.

Table 3 shows the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies in Ogbaru LGA of Anambra State. It indicates that the mean responses of the JS and SS students to items 21, 23 – 25, 27, 29, 31 – 33, and 35 – 40 are in the real limit decision point of 2.50 – 3.49. This implies that the JS and SS students in the secondary schools are aware of the climate change adaptation strategies in those items on a high level. Also, the table shows that the mean responses of JS students to items 22 and 34 are in the real limit decision point of 1.50 – 2.49, while those of their SS students counterparts are in the real limit decision point of 2.50 – 3.49. The implication of this is that the JS students are aware of the climate change adaptation strategies in the items on a low level, while their counterparts in SS class are aware of the climate change adaptation strategies in those items on a high level. The table finally indicates that the mean responses of the JS and SS students to items 26, 28 and 30 are in the real limit decision point of 1.50 – 2.49. It implies that the JS and SS students are aware of the climate change adaptation strategies in the items on a low level. The cluster mean (M = 2.75, SD = .31) and (M = 2.79, SD = .32) for the JS and SS students, respectively, imply that the JS and SS students indicated a high level of awareness of climate change adaptation strategies in Ogbaru LGA of Anambra State, though the SS students obtained a higher mean score than the JS students.

Hypothesis 2: There is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies.

Table 4: t-test scores on JSS and SS students' level of awareness of climate change adaptation strategies in Ogbaru LGA

Group	n	X	SD	df	t-cal	Sig. (2-tailed)	Decision
JS	94	2.75	.31				
				168	-.74	.461	HO_1 Accepted
SS	76	2.79	.32				

Data in table 3 shows the t-test score on the level of awareness of climate change adaptation strategies, t(168) = -.74, p = .461 < .05. Since the p-value of .461 is greater than the 0.05 probability level set for the study, the null hypothesis, which states that there is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies, is accepted. This implies that there is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies in Ogbaru LGA of Anambra State.

Discussion of Findings

The result of the research question 1 revealed that the JS and SS students indicated a high level of awareness of climate change in Ogbaru LGA of Anambra State. The result is against the assumption that those who have basic education (JSS) would be less aware of climate change as compared to other students in SS class, as they are likely to have less access to information and a greater capacity to understand the implications of such a phenomenon. Again, the result agrees with the finding of Eze et al. (2024), which reported that both JS and SS students were aware of the attributes of climate in Enugu State. Also, the corresponding hypothesis one showed that there is a significant difference in the mean responses of JS and SS students on their level of awareness of climate change in Ogbaru LGA of Anambra State in favour of the SS students. Therefore, it means that the level of awareness of climate change could be determined by the level of education.

The study also found that JS and SS students indicated a high level of awareness of climate change adaptation strategies in Ogbaru LGA of Anambra State. It further revealed that there is no significant difference in the mean responses of JS and SS students on their level of awareness of climate change adaptation strategies. This finding is in line with Eze et al. (2024), who posited that JSS and SS students were aware of climate change adaptation strategies. However, the result of hypothesis 2 is against that of Eze et al. (2024), who revealed that there was a statistically significant difference between the mean responses of JS and SS students to the identified climate change adaptation strategies in favour JSS students.

Conclusion

Based on the findings, the study concluded that senior secondary school students showed a more appreciable level of awareness of climate change when compared to their counterparts in junior secondary schools. The study also concluded that both JS and SS students in secondary schools showed an appreciable level of awareness of climate change adaptation strategies. The implication is that those who have a basic education are not less aware of climate change as compared to other students in SS class, as they both have equal access to information and equal capacity to understand the implications of climate change and climate change adaptation strategies.

Recommendations

Based on the findings of this study, the following recommendations were made:

1. The government should, without delay, start organizing workshops and conferences for teachers at all levels on issues of climate change.

2. The government should invest in school infrastructure, such as wind vanes and rain gauges, that could enable the teachers to meet the demands of this era of climate change.
3. The government should start carrying out radio and television campaigns on climate change adaptation strategies.
4. Both public and private schools should form climate change clubs to enlighten the students on the causes and effects of climate change and its adaptation strategies.

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Addressing the self-directed learning culture gap in Kenya's Junior School Science Curriculum

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Abstract

This is a philosophical study and involves conceptual analysis of existing documents on Competency-Based Curriculum (CBC), Kenya's curriculum reforms and self-directed learning culture (SDLC). The study mainly focuses on how the curriculum reforms and curriculum for Kenyan CBC junior schools integrate science, and the current theoretical instructional model has promoted the development of SDLC. The data collected and analyzed is theoretical. This conceptual analysis applies the Kantian critical judgment theory model to analyses the data collected and assess findings using the reflective self-directed instructional model (RSIM). RSIM has standard sub-themes and learning strategies used in assessing SDLC. Key sub-themes and learning strategies used as standard are self-motivation, self-reflection, self-regulation, active learning, metacognition, and collaborative community of inquiry. Key theoretical premises and claims, co-premises, propositions, and supporting evidence are developed using the categories scrutinized and analyzed. According to the analysis, the study reveals a significant gap in the integration of SDLC within the CBC reforms and curriculum design. The study, therefore, proposes a novel instructional model to address this shortfall.

Introduction

This research aims to analyze the structure of the integrated science curriculum for ninth grade as outlined in the Kenyan Competency-Based Curriculum (CBC). A significant emphasis is placed on exploring the gaps in self-directed learning skills, particularly in the context of the COVID-19 school closures, which necessitated that students remain outside the conventional classroom environment where they usually received their educational support.

Rationale of the study

Self-directed learning plays a crucial role in cultivating a mindset geared towards lifelong education, as it enables individuals to assume responsibility for their own learning journeys. This approach not only allows learners to adapt to evolving demands but also enhances their critical thinking abilities, ultimately facilitating the attainment of both personal and professional aspirations. By granting individuals the autonomy to select their own pace, topics, and methods of study, self-directed learning aligns with their unique interests and circumstances. Particularly at basic educational levels, this form of learning significantly boosts motivation and engagement, promotes personalized and flexible study practices, and fosters the development of critical and creative skills, alongside an increase in self-efficacy. Essential components of self-directed learning across all educational levels include the establishment of clear objectives and attainable goals, self-evaluation, proactive exploration of relevant resources, effective time management, and reflective practices. Consequently, it is imperative to equip learners, especially those engaged in integrated science at the basic education level, with the necessary skills for self-directed learning.

Background of the Study

Various adaptations and innovations have emerged globally to facilitate educational access for all learners, whether in traditional classrooms, at home, or in alternative settings. This transformation has been largely prompted by the substantial disruptions to education resulting from the COVID-19 pandemic, which necessitated a departure from conventional learning environments. In response, numerous countries have embraced digital platforms, television, radio, and print media to sustain student engagement with educational materials. However, the implementation of these strategies exhibits considerable variation across nations, and their overall effectiveness

has yet to be comprehensively evaluated (Reimers, 2022). In contrast, lower and middle-income countries, such as Kenya, primarily rely on one-way communication channels like television and radio, with limited participation in online learning platforms such as YouTube, Zoom, Google Classroom, and Google Meet (Ng'ang'a, 2021). Conversely, more affluent nations, including the United States, have predominantly shifted to online classes via various digital learning platforms and have provided educational materials for home use.

The role of households is also crucial in the learning process during periods of school closure. In Kenya, approximately 30% of students from more privileged backgrounds have access to media, internet-enabled devices, books, sufficient time, and adequate study space (Ng'ang'a, 2021). However, according to Reimers (2022) and Punjani & Mahadevan (2021), these learners often lack essential 21st-century soft skills, knowledge, and the ability to study independently and remotely. Conversely, around 70% of learners in Kenya (Ng'ang'a, 2021; UNICEF, 2020) struggle to access such devices, and those who do often have only limited access to radio and television, frequently without adequate guidance from their families (Punjani & Mahadevan, 2021). In light of these challenges, this study aims to explore the potential for fostering a self-directed learning culture (SDLC) that would enable learners, particularly at the junior school levels of the Competency-Based Curriculum (CBC) in Kenya, to engage in learning anytime and anywhere.

Before the onset of COVID-19, secondary school students following the Kenyan 8-4-4 curriculum, which encompasses eight years of primary education, four years of secondary education, and an additional four years for post-secondary studies, were not exposed to essential critical thinking dispositions. The learning outcomes outlined in the Competency-Based Curriculum (CBC) for grades VII and VIII primarily require students to identify, recall, enumerate, and apply knowledge within a classroom setting, which aligns with lower-order thinking skills as categorized by Bloom's taxonomy. The CBC framework has predominantly focused on enumerating the skills and knowledge that students are expected to acquire, neglecting the teaching of dispositions that are fundamental to fostering critical thinking at the junior school level of the educational continuum.

In response to the challenges posed by COVID-19, the Ministry of Education (MOE) articulated nine objectives aimed at alleviating the pandemic's impact on the education sector. However, the development of critical thinking skills for students was conspicuously absent from the emergency response plan, indicating a significant oversight in addressing this vital area during the transition period. The instructional strategies implemented during this time, which included digital and online content as well as broadcasts via television and radio, were executed without adequately

training parents, teachers, and students on the importance of sustained learning amidst the pandemic. Furthermore, the limitations of remote learning in low- and middle-income countries, including Kenya, can be attributed to a lack of knowledge, skills, dispositions, and access to computer-based learning resources. This study aims to assess the impacts of factors such as awareness of the COVID-19 pandemic, computer-based self-efficacy, curiosity, and online teaching and learning on the perceived benefits for learners, which are essential for cultivating a culture of self-directed learning.

Research Gap

The obstacles encountered in the implementation of Kenya's new Competency-Based Curriculum (CBC) due to the COVID-19 pandemic are increasingly being perceived in a more favorable light. Although the expectation is for post-pandemic learning to foster self-directedness among students, the necessary skills, technologies, and information and communication technology (ICT) infrastructure remain insufficient. Current evidence suggests that Kenyan learners are not receiving adequate support in developing critical thinking skills, particularly in the context of limited learning management systems, insufficient digital devices, and a lack of computer literacy and digital infrastructure. This situation presents a significant challenge for a nation aiming to cultivate a culture of self-directed learning among its students. Consequently, there is a pressing need for research focused on the skills and dispositions that could facilitate the establishment of a self-directed learning culture, particularly in the context of integrated science for junior school students. This study aims to critically examine the feasibility of fostering a self-directed learning culture (SDLC) within the framework of Kenya's CBC for junior school learners.

Literature Related to Self-Directed Learning

In order to gain a comprehensive understanding of self-directed learning and the dynamics of teaching and learning within basic educational institutions during the COVID-19 pandemic, a broader study has been conducted. This investigation includes an assessment of pertinent theories and methodologies for analyzing and measuring data, utilizing a standardized self-directed learning model as a framework. While it has not been feasible to encompass the full spectrum of authors in the domain of self-directed learning, the research has successfully established a balanced representation of those whose contributions have significantly shaped the culture of self-directed learning. A substantial majority of educators, exceeding 70%, were found to be inadequately prepared for the transition to remote teaching during the school closures prompted by the pandemic (Wambaria, 2023; Willies, 2023). This lack of preparedness has implications for learners, who are similarly ill-

equipped to engage in self-directed study. Furthermore, the digital infrastructure, devices, and other essential resources for remote education were found to be unreliable throughout the COVID-19 period (Wambaria, 2023). Additionally, learners exhibited deficiencies in critical thinking dispositions (Wairimu & Chilufya, 2022) and the necessary competencies for independent study (Willies, 2023).

Assessing the current basic education theoretical teaching-learning approach

The curriculum for basic education in Kenya is primarily framed through a technical lens. The processes involved in curriculum development and design within this educational framework are predominantly characterized by technocratic and bureaucratic elements, as noted by Heto et al. (2020) and Nganga & Kambutu (2019). This management approach to curriculum preparation and execution, which aligns with the social-behavioral paradigm, typically follows a predetermined logical sequence, with specific objectives and activities designed to achieve these objectives. The communication framework is predominantly hierarchical, reflecting a top-down model. While the Kenyan Competency-Based Curriculum (CBC) for junior school education includes various overarching statements that emphasize the importance of skills development and address contemporary challenges in academia, there remains a scarcity of explicit examples of skills and competency development within the official documents, particularly in the syllabus, as highlighted by Kobiah (2020).

Decisions regarding the curriculum in Kenyan basic education, along with education policies and the necessity for curriculum reform, have traditionally been made by curriculum experts, supervisors at the Kenya Institute of Curriculum Development (KICD), and officials from the Ministry of Education (Akala, 2021). These decisions are then relayed through the bureaucratic hierarchy to essential stakeholders, including teachers, students, and parents (Kobiah, 2020). Within schools, the implementation of these decisions and teaching models is delegated to various departments by headteachers, who serve as curriculum managers. However, despite their pivotal role in the implementation process, headteachers do not possess complete authority over the change process within their institutions (Heto et al., 2020; Nganga & Kambutu, 2017). Their primary responsibility revolves around ensuring compliance with school routines, which includes tasks such as monitoring teacher attendance, maintaining registers, and overseeing examination procedures. In this context, teachers, students, and parents are often viewed as mere components of a rational system, despite the fact that a school functions as a community involving continuous interaction among learners, educators, and administrators (Syomwene, 2020). Unfortunately,

when curriculum specialists design the curriculum, they tend to overlook these vital interactions, leading to a curriculum that lacks evolution, authenticity, and a learner-centered approach, ultimately failing to foster personalized learning experiences for self-directed education.

The developers of the Competency-Based Curriculum (CBC) have integrated constructivism as a foundational learning model, a concept advocated by Dewey's contemporaries (1966) (Akala, 2021; Ongesa, 2020). This educational approach positions the learner at the heart of the knowledge acquisition process. However, Basweti (2019) and Ongesa et al. (2024) contend that the constructivist model is conspicuously absent from the teaching curriculum designed for students in grades V to IX within the new CBC framework. In constructivist theory, the educator's role is redefined as that of a facilitator rather than the primary source of knowledge. Furthermore, constructivism underscores the significant involvement of learners' guardians or parents, emphasizing their critical role in the educational process (Lumonya, 2020). The cultivation of critical thinking, particularly the development of essential critical thinking dispositions, empowers learners to express their thoughts freely and engage in the application, analysis, creation, and acceptance of diverse viewpoints and information, even when such perspectives may conflict with their previously held beliefs.

Ennis (2018) and Sande (2020) highlight in their observations that the absence of learner engagement in the processes of problem identification, content creation, and the formulation of solutions results in knowledge that lacks constructiveness, creativity, and criticality. Consequently, the recently implemented 2-6-6-3 curriculum, which allocates two years for pre-primary education, six years for primary, three years for junior school, and three years for post-secondary education, alongside the previous 8-4-4 curriculum—where students spend eight years in primary, four years in secondary, and four years in tertiary education—has not effectively addressed the cultivation of a self-directed learning culture. This shortcoming can be attributed to the reliance on social-behavioral or top-down management models in educational settings, which have not adequately engaged essential stakeholders in the processes of curriculum development and implementation. Such models prove inadequate in fostering the skills necessary for nurturing a self-directed learning environment within schools.

Critical thinking-based learning model for quality content delivery

Wambaria (2023) and Willies (2023) have identified a significant theoretical and methodological deficiency in the integration of critical thinking within the educational curricula of numerous developing nations, particularly in Kenya. Furthermore, Camilleri & Camilleri (2023) and Zhao & Watterston (2021) highlight that learners globally now have unprecedented

access to a diverse array of content, often at little or no cost, through the internet and digital devices. With the availability of tools such as video cameras and smartphones, students can easily gather and edit digital materials, which can then be incorporated into their academic work. This shift necessitates a transformation in instructional approaches, moving away from the traditional methods of delivering large volumes of information or relying solely on a single textbook for assignments. Instead, educators should facilitate learners in evaluating, applying, locating, and analyzing information pertinent to specific subject areas (Bozdağ & Gökler, 2023; Zhao & Watterston, 2021). The relevance of this information will increasingly be co-constructed between educators and students. A pedagogical model that emphasizes learner autonomy and choice is essential for effective assessment, support, and delivery within universities and primary educational institutions. This study aims to explore existing literature to identify a model that fosters a culture of self-directed learning within the Kenyan Competency-Based Curriculum (CBC) for junior schools and beyond. It has been determined that there is a gap in the current models, and the study intends to propose a robust framework for cultivating a self-directed learning culture in Kenyan CBC junior schools and beyond.

Methodology

The research conducted is a documentary analysis that leverages secondary data sourced from scholars, educational experts, policymakers, and governmental reports to investigate the gaps in the Kenyan Competency-Based Curriculum (CBC) for integrated science at the junior school level. The analysis employs speculative and reflective methodologies to critique and evaluate secondary documents pertinent to the CBC junior school education curriculum in Kenya. This examination encompasses various aspects, including reform reports, pedagogical models, curriculum design, and instructional materials utilized in Kenyan CBC junior schools. Additionally, the study reflects on and speculates about the integration of concepts such as self-efficacy, open-mindedness, a propensity for rational inquiry, inquisitiveness, self-reflection, self-monitoring, and self-control within the design of the CBC education curriculum for integrated science learners at the junior school level. Furthermore, the documents analyzed also address pedagogical strategies and theoretical frameworks that are either currently employed or recommended for fostering a culture of self-directed learning within the Kenyan CBC junior school education curriculum. The data for this analysis were drawn from key documents, including the Kenya Basic Education COVID-19 Emergency Response Plan Report (2020) and the Kenya Institute of Curriculum Development (KICD) curriculum for junior school grades VIII and IX in integrated science (2023). The categories

analyzed serve as a foundation for developing theoretical premises that inform the study's analysis and evaluation.

Study Findings and Analysis

The introduction of a competency-based curriculum (CBC) in 2017 aimed to integrate artificial intelligence (AI) into educational practices, emphasizing skill acquisition over traditional content delivery. However, the implementation of AI has encountered significant obstacles, including a lack of adequate information and communication technology (ICT) devices and infrastructure, compounded by slow and unreliable internet access. Furthermore, the CBC framework has established a system of summative evaluations at the end of each instructional cycle, designed to determine students' readiness to advance to subsequent levels of education.

In the context of Kenyan elementary education, only 120,000 out of 2 million pre-primary students have access to computers and iPads, with a mere 22.4% of this group having internet connectivity. By 2023, 82% of schools reported having power sources, including both mains electricity and solar energy. Notably, only 49,000 students, representing 5% of the 914,000 candidates who sat for the KCSE 2022 examination, participated in computer classes. This scenario indicates a concerningly low level of computer literacy within the Kenyan basic education system. The existing challenges related to ICT infrastructure and digital resources hinder effective management and learning processes. To successfully integrate digital content into educational practices, many teacher educators require access to digital devices, yet the prevailing issues surrounding device availability and internet infrastructure continue to impede progress, resulting in the underutilization of digital resources within educational institutions.

Addressing self-directed learning culture gap in Kenyan CBC Junior School Science

The primary educational goal for ninth-grade students in integrated science classes is to effectively utilize literacy, scientific knowledge, and principles to develop appropriate scientific skills and practices applicable to everyday life. To address scientific challenges encountered in daily situations, students are required to integrate their scientific knowledge, skills, values, and attitudes. Achieving specific learning outcomes is essential for junior high school students in integrated science, as it equips them with critical thinking and problem-solving capabilities. Students should enhance their skills in manipulation, management, conservation, hygiene, sanitation, and interpretation through a scientific approach that fosters creativity and effective problem-solving. Furthermore, it is imperative for students to apply scientific principles, knowledge, and foundational skills to resolve scientific issues

across various contexts. The integrated science curriculum is designed to impart knowledge of science, scientific skills, and principles; however, it does not adequately address the development of critical thinking dispositions and criticality within the ninth-grade curriculum for junior high school students.

The educational goals for integrated science encompass the acquisition of scientific knowledge, skills, and concepts aimed at environmental preservation, personal hygiene maintenance, and the establishment of effective scientific methodologies for environmental control. Students in junior school, particularly those in grade nine, are expected to develop specific scientific competencies, including manipulation, environmental management, conservation, sanitation, nutrition, and natural interpretation. However, the curriculum does not emphasize the cultivation of critical thinking dispositions or self-efficacy skills. The overarching objectives of the integrated science course fail to incorporate essential elements such as self-monitoring, self-management, self-reflection, open-mindedness, and curiosity, which are vital for fostering a self-directed learning culture and enhancing critical thinking, as highlighted by Roeniger (2023).

While self-efficacy is briefly mentioned in the context of force and energy and the study of curved mirrors, it plays a significant role in the learning process. For instance, when ninth-grade students engage in discussions about the characteristics of images produced by curved mirrors, they not only practice leadership but also enhance their self-efficacy. This term refers to the confidence learners possess when facing challenging tasks or questions during their educational journey. Although peer discussions are common, they do not equate to the development of self-efficacy. The assessment of self-efficacy levels reveals a notable gap in the critical thinking dispositions necessary for fostering a self-directed learning culture within integrated science curricula.

The design of the integrated science curriculum for junior school students is deficient in essential competencies necessary for the development of Systems Development Life Cycle (SDLC) and critical thinking, beyond merely imparting scientific knowledge, principles, and skills. Key abilities such as manipulation, environmental management, conservation, sanitation, nutrition, and nature interpretation are notably absent. According to the findings of the study and the Elder-Paul (2019) model for assessing SDLC, the integrated science curriculum outlined by KICD (2024) lacks several critical thinking dispositions, including role-playing, active learning, inquiry-based learning, modeling thought processes, utilizing tools to enhance cognitive engagement, collaborative learning, real-world application, visualization and prediction, as well as writing skills. This deficiency suggests that the integrated science curriculum for ninth-grade students not only fails to cover all critical thinking indicators but also does not equip students with

the necessary skills to effectively develop SDLC and critical thinking. Consequently, without these additional competencies, the teaching of manipulation, environmental management, conservation, sanitation, nutrition, and nature interpretation cannot adequately facilitate the comprehensive development of SDLC. Thus, it is clear that a significant gap exists in the promotion of SDLC among junior school learners engaged in integrated science education.

The primary inquiry topics within the integrated science curriculum, such as mixtures, elements, and compounds; living organisms and their environments; and force and energy, do not emphasize critical thinking. For example, when exploring the concepts of mixtures, elements, and compounds, students are prompted to engage with specific inquiries that may not foster a critical thinking approach.

What importance does the structure of an atom hold? Students are encouraged to create models of specific elemental atoms utilizing locally accessible materials. Given the complexity of real atoms and the advanced techniques required to manipulate them, they can only be observed through an electron microscope, which is typically found in national science centers. The act of modeling a hypothetical atom serves to stimulate creativity. However, according to Bloom's taxonomy, such imaginative tasks are considered lower-order skills and do not contribute significantly to the enhancement of critical thinking and the Software Development Life Cycle (SDLC) in students.

For ninth-grade learners in an integrated science curriculum, several inquiry questions pertinent to the theme of living organisms and their environment are proposed: Why is hard water preferred for consumption? What is the significance of photosynthesis in the ecosystem? How does the human body process food? To evaluate the conditions necessary for photosynthesis, students are expected to conduct experiments and share their findings in class. Engaging in experimental or manipulative activities fosters critical thinking and creativity. It is essential to assess the learner's understanding of photosynthesis, regardless of prior coverage of the topic. A reflective and analytical student can explore and verify the conditions for photosynthesis even without direct inquiry into the subject.

Students are encouraged to articulate their knowledge and understanding of the human digestive process while also engaging with the perspectives of their peers. Listening may occur primarily when students are prompted to recall previously learned information or when they acquire knowledge at an early stage, often in the absence of practical application. Within Bloom's taxonomy, the act of remembering is classified as a lower-order cognitive skill. The development of critical thinking and the Software Development Life Cycle (SDLC) cannot be effectively achieved through techniques that rely solely on lower-order thinking.

The inquiry questions proposed for the force and energy strand, which students are expected to address, include: what are curved mirrors and their applications in everyday life, and how are waves utilized in daily activities? These questions, along with other significant inquiries for ninth-grade integrated science, are structured to elicit specific responses from students. Such guided inquiries are typically closed-ended, which limits the potential for fostering open-mindedness a crucial component of critical thinking. The absence of open-ended questions in the proposed major inquiries indicates a shortfall in the development of critical thinking skills within the integrated science curriculum for junior school students in the Kenyan Competency-Based Curriculum (CBC).

A learner who successfully meets or surpasses assessment criteria should not only have a solid foundation in scientific knowledge but also demonstrate competencies in management, manipulation, conservation, experimentation, and nutrition. While the suggested inquiry questions for ninth-grade integrated science students may aid in fostering critical thinking skills, there is a noticeable deficiency in student curiosity. The predominant use of "how" and "what" as the initial prompts for most proposed inquiry questions suggests a lack of depth and engagement. Furthermore, it is essential that students generate inquiry questions driven by genuine curiosity rather than solely relying on the subject matter or the instructor. This reliance indicates a significant shortfall in the integrated science curriculum for ninth graders, particularly concerning the critical thinking components necessary for the Skills Development and Learning Competencies (SDLC). Consequently, there exists a notable gap in the integrated science and Competency-Based Curriculum (CBC) frameworks for junior schools.

Moreover, the integrated science curriculum for ninth-grade students does not address the development of self-efficacy, a vital aspect of critical thinking that encompasses self-confidence. The current CBC framework fails to incorporate essential critical thinking dispositions such as open-mindedness, inquisitiveness, truth-seeking, and self-efficacy. Given that these dispositions are integral to critical thinking indicators and the SDLC, the absence of such elements in junior school integrated science activities signifies a deficiency in fostering critical thinking skills. As a result, the integrated science curriculum for junior school students is inadequate in promoting critical thinking and SDLC. The lack of focus on critical thinking indicators within the curriculum may hinder a junior high integrated science student's ability to engage in critical thought, with discussions surrounding the development of these skills being only superficially addressed.

The lack of critical engagement among learners can be attributed to the absence of expectations for them to voluntarily participate in study projects that would benefit both themselves and society. Participation in integrated

science initiatives that promote learning and address societal challenges, such as hearing loss and vision impairment, exemplifies the critical engagement that is currently lacking among students. In the context of the integrated science curriculum for ninth-grade junior school students, critical engagement is notably absent. While the curriculum is a significant aspect of fostering critical thinking, it does not adequately address this deficiency. Ninth-grade students are tasked with developing community service projects, which require them to identify community issues and formulate solutions. Through this process, they are expected to acquire knowledge, skills, values, and attitudes pertinent to community service. However, the integrated science curriculum for these students is deficient in essential critical thinking skills, such as effective writing, collaborative inquiry, active learning, expert modeling, creativity, and practical skills. This shortfall suggests that the curriculum either overlooks or inadequately incorporates the fundamental elements of critical thinking. Furthermore, the community service assignments lack critical thinking attributes, including open-mindedness, curiosity, truth-seeking, and self-efficacy. Consequently, the absence of these critical thinking indicators hinders the potential for community service programs to enhance students' critical thinking abilities and foster sustainable development learning competencies (SDLC). Thus, there exists a significant gap in critical thinking dispositions among ninth-grade integrated science learners within the Kenyan Competency-Based Curriculum (CBC).

The curriculum report does not mandate that a ninth-grade student in integrated science must independently plan and execute their community service project. This suggests that any individual from the student's family or community may select the project, carry it out, or assist the student in its completion. If the individual who assigned the project also instructs the student on how to present it in class, the student may fail to achieve the intended goals of the project. Furthermore, the curriculum report lacks a clear framework for educators to assess the authenticity of the community service projects undertaken by students in integrated science courses. The evaluation process for these projects should provide guidance to instructors on how to verify the legitimacy of the completed work before making judgments about whether a student has met, exceeded, approached, or fallen short of the established expectations.

Addressing the self-directed learning culture gap in Kenyan CBC Junior school science curriculum using a standard model

In order to conduct a thorough evaluation of the analyzed documents, the research utilized a self-directed teaching-learning framework known as the Reflective Self-directed Instructional Model (RSIM), which is also referred to as the multiliteracies self-directed learning model. The authors Mentz,

Laubscher, and Olivier (2021) undertook a comprehensive review of existing self-directed teaching-learning models, identifying deficiencies in prior frameworks, which led to the development of RSIM. This model encompasses various themes, sub-themes, and essential components that are crucial for a self-directed learning curriculum, enabling learners to take charge of, manage, and oversee their educational experiences independently. The learning strategies of self-directed learners, as articulated within the RSIM framework proposed by Mentz, Laubscher, and Olivier (2021), are succinctly presented in Table 1 below.

Table 1: Reflective SDLC for a self-directed learning elements

Common themes	Common Sub-themes	Learning strategy (The role of the SDL learner)
Competency and commitment to self-directed learning	Self-motivation Self-monitoring Self-control Self-reflection	● Open-ended activities and assignments. ● Active learning ● Mind-mapping ● Formulating research or inquiry-based questions. ● The completion of projects, reports, and portfolios, allowing learners to exhibit their knowledge and skills effectively. ● Selection of medium to communicate their competencies: Writing, speaking, visual presentations, multimedia, or other formats. ● Collaborative communities of inquiry.

Mentz, Laubscher, and Olivier's (2021) Reflective Self-directed Instructional Model (RSIM) serve as a foundational framework in this research for evaluating the Self-Directed Learning Culture (SDLC) within junior school education curricula, with a particular focus on integrated science programs. The analysis of competency-based curriculum documents related to junior school integrated science, which includes reform reports on CBC, the integrated science curriculum, and the emergency response plan for education during the COVID-19 pandemic, is conducted through the lens of the RSIM. This examination reveals recurring themes and pedagogical strategies that are essential for fostering a self-directed teaching and learning environment, as detailed in Table 1.

The study further illustrates how these identified sub-themes and learning strategies pertinent to a self-directed learning culture are contextualized within the Kenyan CBC junior school integrated science curricula. Notably, a significant number of these sub-themes are either missing or insufficiently articulated in the Grade IX curricula of the Kenyan CBC, as previously analyzed. Key learning strategies that support a self-directed learning culture, such as digital literacy, goal setting, student-generated

inquiry questions, real-life experiences, and collaborative community studies, are notably absent. Additionally, strategies like modeling, role-playing, competency demonstrated through completed projects and portfolios, open-mindedness, self-monitoring, and real-life experiences are inadequately developed within the design of the Kenyan CBC junior school integrated science curriculum.

Research has indicated that students in Kenyan CBC junior schools face significant challenges in speaking, writing, and overall communication skills. The analysis presented earlier in this paper highlights the inadequate and uneven distribution of digital devices and infrastructure throughout the country, affecting schools and families alike. The educational objectives are predetermined for learners, which diminishes their ability to exercise self-regulation over the problems or projects assigned to them. Furthermore, the inquiry questions provided to students are fixed, leaving no opportunity for them to propose their own questions or enhance those already established. This situation restricts learners' curiosity and open-mindedness in both question formulation and response strategies. Additionally, the curriculum design lacks evidence of engaging students with real-world experiences or relevant issues. In the context of the grade IX curriculum, which includes topics such as mixtures, elements and compounds, and force and energy, students are not adequately exposed to practical experiences related to these concepts. While some aspects of mixtures and living organisms are addressed, the connection to real-life applications remains superficial, preventing learners from visualizing essential scientific principles. For instance, while students are required to memorize the symbols and atomic numbers of elements like iron, sodium, and chlorine, such abstract learning does not foster genuine curiosity or promote self-directed learning.

The absence of modeling self-control, self-reflection, and self-monitoring by instructors significantly undermines the effectiveness of completed projects, as students often lack these essential skills in managing their work. This deficiency leads to challenges in verifying the authenticity of students' outputs, particularly when poor language skills and dialectical issues hinder their ability to communicate effectively. Consequently, students who struggle with writing may exhibit a lack of curiosity, which in turn diminishes their capacity for self-directed learning during instructional activities. To address this issue, it is crucial to nurture and instill curiosity within students. Implementing Socratic questioning in small collaborative inquiry groups, where diverse perspectives and assumptions are explored, can effectively enhance students' curiosity. Such an approach encourages educators to transcend conventional understandings by clearly defining existing knowledge and promoting innovative concepts through creative learning experiences. It is advisable for educators to prioritize curiosity and an inquiry-based

methodology in their lesson planning and delivery, as this strategy fosters the generation of new ideas and encourages reflective thinking. When students engage in small, cooperative inquiry groups, they critically examine and evaluate the assumptions related to specific tasks, creating a supportive environment that bolsters self-efficacy. In these collaborative settings, students' creativity and self-efficacy are likely to flourish as they share and develop their ideas alongside peers with differing viewpoints.

Effective Self-directed Learning Culture Strategies

The focus of this discussion is on learner-centered, non-formal online learning, which is identified as a crucial and effective strategy for self-directed learning. The subsequent section will evaluate and elaborate on these learning strategies.

Learner-Centered, and Non-Formal Online Learning

Self-regulated instructional models should be embraced in the post-COVID-19 educational framework, moving away from traditional teacher-directed approaches. The essence of genuine self-motivated and self-regulated learning lies in the ability of learners to forge their own unique and thoughtful educational journeys, thereby fostering a culture of self-directed learning. This approach enables students to acquire knowledge that resonates with their personal interests and strengths. To facilitate this, the curriculum must not only incorporate essential critical thinking skills but also empower students to shape their own learning experiences without excessive constraints imposed by predetermined content or instructor directives.

Empowering students with ownership of the curriculum not only enhances their individuality but also affirms their rights as autonomous learners, thereby nurturing a self-directed learning environment. Such a curriculum allows students to propose innovative course materials, make informed choices, and accept the consequences of their decisions. Furthermore, it encourages students to take charge of their educational journey by engaging with the subject matter, exploring relevant issues, identifying potential solutions, and cultivating lifelong learning skills and habits.

Students have the opportunity to access a diverse array of free, multi-source, and site-specific educational resources relevant to their fields of study through various platforms, including the Internet, virtual laboratories, and traditional classroom environments. With the advent of technology, learners are equipped with devices such as video cameras, AI-enabled smartphones, tablets, and personal computers, which facilitate their engagement with virtual information and data that can be tailored for academic assignments. To enhance the effectiveness of learning, educators should move away from delivering content in large, unmanageable segments, such as extensive

chapters or singular textbooks, and instead foster a collaborative approach where both teachers and students assess the relevance and applicability of the materials.

In this context, it is crucial for students, particularly those in Kenya's CBC junior schools studying integrated science, to be allowed to bring portable internet-enabled devices into the classroom, including smartphones and video cameras, provided they have received adequate training in self-directed learning. Self-directed learners possess the ability to identify and utilize resources that are both beneficial and challenging, which are often not readily available through social media channels. Characteristics such as independence, self-awareness, and self-reliance define self-regulated learners. Research indicates that these devices serve as effective tools for tasks involving pattern recognition, repetition, and memorization, which are essential for information gathering, storage, and retrieval. However, it is important to note that these activities represent lower-order thinking skills and do not contribute significantly to the development of self-directed learning, as they do not necessitate rigorous classroom engagement.

Individual critical thinking, human values, and humanity will be the most important commodities that set humans apart from those lacking them in a world of artificial intelligence. Because of this, it's critical to foster in students a culture of self-directed learning from an early age in basic education settings (primary and secondary schools). Since the future is unpredictable, unclear, and ever-changing, it is crucial to foster traits like curiosity and self-efficacy. Learners will become critical thinkers if more time is allotted for more engaging activities that can foster the growth of a self-directed learning culture in them rather than just having them recollect and retrieve knowledge that can be done quickly by AI gadgets. In Kenyan CBC junior schools, curiosity and open-mindedness that foster self-directed persons should be promoted.

This study analysis and Roeniger's (2023) study on 'cultivating learning throughout life' which has observed that Massive Open Online Courses (MOOCs) and Online Education tools (OER) are two recent innovations in the field of education that provide learners with tools to enable and promote their independence during non-formal learning. Peer discussions, automated testing, and grading will give those students feedback and encouragement on their subject of study. This is also feasible if instructors have inspired students to consider ideas that are pertinent to their field of study. These chances for independent, non-formal online learning are anticipated to address any learning gaps that may have arisen during, particularly in the wake of, the COVID-19 pandemic and its aftermath. When we implement remote or online learning in our junior school and senior school

going forward, we also need to instill a strong self-regulated learning culture in those students so they can make informed material choices.

Discussion and summary of study findings

The thesis that there is a gap in SDLC revealed by the introduction of COVID-19 is strengthened by this study. To encourage the development of the SDLC, it implies that educators and students require support as well as a phrasing paradigm that makes use of important critical thinking dispositions as a unifying theme. The degree to which SDLC had been promoted during instructional delivery by Kenyan educators in schools, how key critical thinking dispositions (CTD) in the current instructional model in Kenya's CBC junior school integrated science curriculum design, and the suitable instructional model that promotes SDLC in junior schools are addressed.

The majority of common themes found in self-directed learning cultures, such as important dispositional aspects of critical thinking, competency and commitment, the development of conviction as a value, and the desire to foster such a culture, are either absent from the Kenyan CBC junior grade IX education curricula or are discussed in a way that is too general to foster the growth of a self-directed learning culture. The curriculum modifications examined also lack the majority of common sub-themes, such as truth-seeking, curiosity, open-mindedness, self-motivation, self-management, self-control, and small collaborative communities of inquiry. The examined categories also lack self-directed learning techniques like digital literacy, speaking, writing, and communicating, as well as experiences from real life, role-playing, modelling, active learning, community study or collaboration, and Socratic questioning. As a result, the current teaching-learning paradigm for the grade IX junior school integrated science curriculum has a self-directed learning culture gap.

The Kenyan CBC junior school grade IX curriculum does not yet include the problem-based learning (PBL) approach. Many elements must be in place for problem-based learning to occur, including students' self-determination, skillfully built teams or communities of inquiry, knowledgeable tutors, well-structured problems, activation of past knowledge, and group dynamics. The majority of these elements are absent from the Kenyan CBC junior school curriculum reports examined. A portion of the existing components has also not been implemented in the process of curriculum instruction delivery.

It is necessary to clarify how a self-directed learning culture and essential critical thinking dispositions are to be developed in Kenyan schools for students enrolled in the CBC junior school integrated science education curriculum, as well as other curriculum reform reports. To foster a culture of self-directed learning throughout all school curricula, the Kenyan curriculum

needs to be changed to incorporate common themes, sub-themes, and learning strategies that are covered early on. For instance, individual learning can be done when learners are placed in small learning communities of inquirers with a welcoming environment, instructions, and tasks that are somewhat challenging to solve on their own utilizing an inquiry-based strategy, using constructivism as a learner-centred epistemological approach.

According to the logical analysis, a school's culture of SDLC is established by its teachers' competence, commitment to advancing the development of SDLC, integration of SDLC into all programs, and school-wide practice. The qualities of educators who can support the development of SDLC in a school include being competent in key critical thinking dispositions (CTD) and having a commitment to creating SDLC. School-wide SDLC practice development and the advancement of SDLC in the majority of school programs are related to the creation of a school-wide practice of SDLC. Therefore, Kenyan CBC junior schools must create a school climate that values critical thinking abilities as well as self-monitoring, self-reflection, and self-motivation. All stakeholders in the school must participate in programs that foster a culture of self-monitoring, self-reflection, self-motivation, and critical thinking.

All students should be guided through thought-provoking activities that let their minds roam and grow so they may more easily deal with the challenges they encounter. This calls for a paradigm that makes use of essential dispositional elements of critical thinking to help students reflect on what they have learned and exercise self-control over how they study, explore, and deal with obstacles in life. To assist learners become self-directed, it is vital to foster an environment that supports and encourages self-motivation, self-reflection, self-monitoring, self-efficacy, open-mindedness, truth-seeking, and curiosity. An individual's critical thinking dispositions, knowledge, competency, and commitments, as well as their intended results and convictions, can all be used to establish a self-directed learning culture (SDLC). Additionally, this study's research reveals that teachers who are keen to promote a culture of self-directed learning should be curious, open-minded, truth-seeking, and self-assured. Content that stimulates readers' curiosity may aid them in becoming more independent learners throughout the teaching-learning process.

Several challenges might arise when attempting to establish a self-directed learning culture (SDLC) for students in Kenyan schools, particularly regarding classroom layout, scheduling, location, and even tenure for those tasked with fostering this kind of learning. To create a culture of self-directed learning throughout the school, time is needed to personalize the sessions and obtain pertinent materials. The responses, competency, and dedication of the learners should determine the direction of the discussions. It might take a bit

longer to generate competent, self-directed, critical-thinking students who are also devoted, but only if the educational system is less exam-focused.

Conclusion

Kenya's CBC junior school curriculum has not specified how to encourage the growth of a self-directed learning culture. The examined curriculum reports should include common themes, sub-themes, and learning practices that lead to the development of a self-directed learning culture in schools. According to the study analysis, the competency and commitment of all school stakeholders to SDLC, the formation of SDLC belief, the desired goals of SDLC learners, and important critical thinking dispositions are essential common themes to self-directed learning. Self-monitoring, self-reflection, self-motivation, self-control, self-regulation, and self-management are sub-themes that lead to competency and commitment. Curiosity, open-mindedness, self-efficacy, and truth-seeking are sub-themes to critical thinking dispositions that are underdeveloped in basic learning institutions, where the junior school is shelved. The Kenyan curriculum's current instructional approach includes a clear road map for fostering the creation of SDLC in classrooms. A new model is needed to guide this process.

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