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Respectfully,

Alexandru TĂBUȘCĂ, PhD

JISOM Editor-in-Chief

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TABLE OF CONTENTS

RDF AND WEB SERVICES: CORNERSTONES OF THE SEMANTIC WEB EVOLUTION

Adam ALTĂR-SAMUEL[1]

Abstract

Despite being a relatively recent innovation, the World Wide Web has undergone rapid expansion, profoundly influencing society on a global scale. At its core, the Web is a vast network of interconnected documents primarily designed for human consumption, making it challenging for machines to interpret and process this information autonomously.

The Semantic Web emerges as a transformative extension of the current Web, aiming to bridge this gap. By enabling information to be structured in a way that machines can interpret, the Semantic Web facilitates seamless machine-to-machine communication and interaction, opening new possibilities for automation, efficiency, and intelligence in handling digital information.

This paper explores the intrinsic relationship between the Semantic Web and Web services, highlighting how these technologies work in tandem to enhance machine interpretability. It delves into the pivotal role of supporting technologies, such as RDF, SPARQL, and ontologies, in enabling this interaction. Through this analysis, the paper underscores the potential of these innovations to revolutionize information exchange and interoperability on the Web.

Keywords: Semantic Web, web services, RDF (Resource Description Framework), SPARQL, WSDL (Web Service Description Language), OWL (Web Ontology Language)

JEL Classification: L86

1. Introduction

The **Semantic Web** represents an advanced extension of the current World Wide Web, designed to facilitate the searching, usage, and integration of data in a more seamless and efficient manner. At its core, it relies on metadata expressed in a machine-readable language, specifically the **Resource Description Framework (RDF)**. This approach

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allows data to be structured in a way that machines can interpret, enabling the automation of complex processes.

The fundamental idea behind the Semantic Web is to address the challenge of managing the ever-increasing volume of data available on the Internet. Currently, most web content is designed primarily for human consumption, making it difficult for machines to process and differentiate between relevant and irrelevant information. This difficulty arises due to the diversity of content types and formats, as well as the varied contexts in which users interact with the web. The Semantic Web aims to bridge this gap by providing an environment where information is enriched with precise, machine-interpretable meanings.

By complementing the traditional web, the Semantic Web envisions a future where software agents can handle sophisticated tasks. In such an environment, information will be not only displayed but also "understood" by computers. This could enable machines to autonomously process, reason, and act upon data in ways that were previously unimaginable.

The concept of the Semantic Web was introduced by **Tim Berners-Lee**, the inventor of foundational web technologies such as the **World Wide Web (WWW), Uniform Resource Identifier (URI), HyperText Transfer Protocol (HTTP)**, and **HyperText Markup Language (HTML)**. His vision for the Semantic Web extends the capabilities of the current web to enable more meaningful interactions between humans and machines.

One promising application of the Semantic Web is in the field of **e-Learning**. Its unique characteristics, such as the precise definition of concepts and the ability to process metadata automatically, open up new possibilities for educational innovation. Through the use of appropriate software agents, learning materials can be semantically interpreted, reorganized, and adapted to meet individual user requirements. For instance, users could request personalized learning modules, and the system would dynamically combine relevant information based on their preferences and learning objectives.

This process is powered by **ontologies**, which provide structured definitions of concepts and relationships within a given domain. By leveraging these ontologies, users can navigate and query learning materials semantically, creating an intuitive and efficient learning experience.

Despite its potential, the Semantic Web is still in its early stages of development. While its future appears promising, debates continue regarding its direction and the specific features it should prioritize.

Currently, much of the information available on the web is presented in **HTML** format, which, while useful for human readers, poses limitations for machines. For example, a **Google search** typically retrieves only about 25% of the total relevant results for a given query. In some cases, relevant information might not appear in search results at all, even when it exists online.

A common example of this limitation is the difficulty in extracting and reusing data from sources such as weather updates, local events, or TV schedules. While these types of information are readily available in HTML, gathering only the necessary data and repurposing it for use in another context often proves challenging.

The technologies underpinning the Semantic Web aim to address these challenges, offering a more structured and interconnected web experience. By enabling machines to interpret and manipulate data with well-defined meanings, the Semantic Web has the potential to revolutionize how we interact with information across numerous domains.

2. Web Semantics

To facilitate the development of the **Semantic Web**, a specialized language was created to structure data in a way that machines can easily interpret and process. This language, known as **RDF (Resource Description Framework)**, operates using a triplet format analogous to the components of a sentence: **subject**, **predicate**, and **object** (or complement). The primary goal of RDF is to standardize how "machine-understandable" data is transmitted and received across systems.

RDF is built on **XML (eXtensible Markup Language)**, which offers a well-established foundation for structuring and parsing data. Since many XML parsers are already available, processing RDF data is straightforward once the information is encoded in this format. By expressing data in RDF, it becomes easier for machines to work with complex information sets.

For the Semantic Web to reach its full potential, data needs to be published in RDF. Through RDF documents, users can define objects with specific properties and establish relationships between them. A significant feature of RDF is its reliance on **URIs (Uniform Resource Identifiers)** to uniquely identify data, ensuring that concepts are not merely abstract words but are tied to explicit definitions accessible online via their URI. This unique identification eliminates ambiguity, fostering greater precision in data interpretation. [1]

2.1. Example of RDF in Action

Imagine a database containing information about individuals and their respective cities of residence. If a software agent needs to identify all individuals living in a specific city, it must "understand" that the **City** field contains the relevant information. Using RDF, this relationship can be explicitly defined, allowing the agent to locate the desired data effortlessly.

2.2. The Role of Ontologies in the Semantic Web

Another critical component of the Semantic Web is **ontologies**. Ontologies provide a framework for defining relationships between terms, enabling seamless integration of data from disparate sources. While the term ontology traditionally refers to the philosophical study of existence and being, in the Semantic Web context, it denotes a file or schema that describes the relationships among concepts.

Consider two databases: one containing fields such as **Name**, **Surname**, **Street**, and **City**, and another with fields like **Full Name** and **Address**. Although these databases represent the same type of information, their differing structures create challenges for applications attempting to interact with both. Ontologies bridge this gap by defining equivalencies between concepts, allowing the application to "understand" that **Full Name** is equivalent to **Name + Surname**, and **Address** corresponds to **Street + City**.

Ontologies typically consist of two key components:

- **Taxonomies**: These define classes of objects and their relationships. For example, an **address** may be classified as a type of **location**, and a **zip code** is only relevant to locations. Subclasses inherit the properties of their parent classes, enabling the modeling of complex hierarchies.
- **Rules of Inference**: These rules enable applications to deduce new relationships from existing ones. For instance, if a person lives on a specific street and that street is part of a particular city, the application can infer that the person lives in that city.

Ontologies enhance web functionality in several ways, including improving search results. Rather than relying on keywords, search engines using ontologies can identify pages based on well-defined concepts, significantly improving precision and relevance. Advanced applications can use ontologies to "understand" complex definitions, paving the way for smarter and more efficient systems. [2]

2.3. Protégé: A Tool for Creating Ontologies

One of the most widely used tools for creating ontologies is **Protégé**, developed by Stanford University. This application stands out for its flexibility and alignment with Semantic Web standards. It allows users to define intricate ontologies that meet diverse requirements. [3]

2.4. The Semantic Web in Action

The true potential of the Semantic Web will be realized when intelligent agents—applications capable of collecting, processing, and exchanging data—become widespread.

These agents will thrive as the volume of machine-readable data grows, enabling increasingly sophisticated interactions. A cornerstone of their functionality will be the ability to exchange "proofs" in a unified language of the Semantic Web. This language will allow agents to perform logical inferences based on rules and ontologies.

For example, suppose an agent retrieves information about a person, **X**, living in Bucharest. To verify the accuracy of this information, the agent can query the source, requesting additional proof or a list of relevant references. Although this unifying language is still under development, early versions are already enabling basic data exchanges between applications.

2.5. A Practical Scenario

Consider a user who wants to plan a vacation in London. By simply entering the request, "I want to go to London on holiday from the 8th to the 15th of September, 2025," a Semantic Web-enabled application could process the query using RDF and ontologies. The application would identify the need for flight bookings and hotel reservations, automatically interacting with relevant services to make arrangements. It could also suggest additional activities or services based on the user's preferences, creating a comprehensive and personalized itinerary.

2.6. The Role of Digital Signatures

To ensure trust and security, digital signatures will play a crucial role in the Semantic Web. These encrypted identifiers verify the authenticity of information sources, preventing fraud. For instance, if an agent processes a payment, it must confirm that the transaction is directed to the intended bank, not a malicious actor. Agents will adopt a cautious approach, verifying data through digital signatures before taking action.

2.7. The Future of the Semantic Web

When fully realized, the Semantic Web has the potential to revolutionize how we interact with information online. By enabling efficient data exchange, logical reasoning, and enhanced trust, it will offer a transformative web experience. A key driver of this revolution will be **web services**, which represent one of the most advanced and developed aspects of the Semantic Web today. These services provide the backbone for seamless integration and automation, paving the way for a smarter, more interconnected web.

3. Web Services

The relationship between the World Wide Web (WWW) and user-software interactions parallels the anticipated role of Web Services in facilitating seamless software-to-software interactions.

A **Web Service** is a software system designed specifically for exchanging information between machines over a network. It acts as an interface that defines a set of operations, or functions, accessible via **XML (eXtensible Markup Language)** messages. This standardized approach allows disparate systems to communicate effortlessly.

Web services are described by files written in **WSDL (Web Service Description Language)**, which contain all the information needed to interact with the service. These descriptions specify details such as message formats, transport protocols, and service locations. By encapsulating the technical implementation, web services enable users to interact with them without concern for the underlying hardware or software platforms. This abstraction ensures platform independence and reusability across diverse applications.

3.1. The Role of Agents in Web Services

While a web service itself is an abstract concept, it must be implemented by a tangible agent—an application responsible for sending and receiving data. Multiple agents, developed in various programming languages, can interact with the same web service, utilizing its functionality. The communication protocol and data formats used by a web service are precisely defined in its WSDL file, which standardizes the interaction process.

3.2. Web Services in the Semantic Web

The utility of web services becomes particularly evident within the context of the Semantic Web. Consider a scenario where a user wishes to book a flight from Bucharest to Hamburg for a specific date and pay using a Maestro debit card. Typically, the user would need to search for a suitable website, browse its offerings, and manually input data. However, with semantically described web services, this process can be automated.

Semantic descriptions of web services, written in a machine-readable format, enable software agents to discover and interact with services based on specific criteria. These descriptions can be stored in **service registries** or found via web crawlers, making it possible for agents to locate services dynamically.

3.3. Web Service Architecture

Web service architecture revolves around the interaction of three key entities:

- **Service Provider**: The platform that hosts the web service.

- **Service Registry**: A directory of web service descriptions that users can search.
- **Service User**: The application or agent that interacts with the service.

These entities perform three main operations:

- **Publishing**: The service provider publishes the web service description, either directly to a user or through a service registry.
- **Searching**: The service user searches the registry for web services matching specific criteria.
- **Binding**: After locating the appropriate web service, the service user connects to and interacts with it using the provided WSDL description.

This architecture ensures a systematic process for discovering, accessing, and utilizing web services.

3.4. The Lifecycle of a Web Service

To deploy and maintain a web service, the following stages are essential:

- **Design and Implementation**:
  - Create the service functionality and its corresponding WSDL description.
  - Test the service for correctness and compatibility.
- **Deployment**:
  - Host the service on a platform, such as a web server.
  - Publish the WSDL file, making it available to users and registries.
- **Runtime Operation**:
  - Once deployed, the web service becomes operational, allowing users to query and interact with it.
- **Maintenance**:
  - Regular updates and optimizations ensure the service remains relevant and meets evolving user needs.

3.5. Use Case Example

Imagine an Internet Service Provider (ISP) hosting a web service that offers flight booking functionality. The ISP defines the service's WSDL file and publishes it in a service registry. A user application, searching for flight booking services, discovers the WSDL entry,

connects to the service, and uses it to retrieve flight options and complete a booking. The entire process—from discovery to interaction—is streamlined, thanks to the standardized structure of web services.

3.6. Advantages of Web Services

Web services offer a multitude of benefits, including:

- **Platform Independence**: Applications written in any programming language can interact with web services.
- **Dynamic Discovery**: Agents can locate and bind to services based on real-time requirements.
- **Interoperability**: Standardized formats like WSDL and XML ensure seamless communication across diverse systems.
- **Scalability**: New services can easily be integrated into existing frameworks.

By enabling efficient, automated software interactions, web services are poised to become a cornerstone of the Semantic Web. Their ability to dynamically discover, describe, and execute operations will significantly enhance the functionality of applications, ensuring the rapid and accurate exchange of information. As these services evolve, their impact on both developers and end-users will grow, fostering a more connected and intelligent digital ecosystem.

4. RDF Query Languages

The **Resource Description Framework (RDF)** is widely regarded as the most significant standard for data representation and exchange in the Semantic Web. Its adoption implies the creation and utilization of vast RDF databases that need to be efficiently searched and queried. While traditional relational databases using SQL could theoretically manage such tasks, the approach is impractical. This is because SQL's syntax is rigid and limited, whereas RDF structures data in the form of triples (Subject, Predicate, Object), which is fundamentally different from the tabular model used by relational databases.

To address these challenges, specialized **RDF Query Languages** have been developed. These languages are designed specifically for querying RDF data, providing greater flexibility and efficiency than SQL.

4.1. The RDF Data Model

At its core, RDF represents data as a collection of triples:

- **Subject**: The resource being described.
- **Predicate**: The property or relationship of the resource.
- **Object**: The value or another resource related to the subject.

This structure forms an **RDF graph**, where triples are edges connecting nodes (resources). The RDF data model is independent of any specific serialization format, meaning that query languages operate on the graph structure itself rather than serialization-specific details like order.

RDF's formal semantics provide a solid foundation for reasoning about the meaning of its data. This reasoning, known as **entailment**, allows implicit information to be inferred from explicitly stated triples. Query languages may support entailment and offer ways to differentiate between explicit and implicit data. [4]

4.2. Characteristics of RDF Query Languages

An RDF query language is typically defined by five key properties [5]:

- **Expressiveness**
    - This refers to the ability of the language to formulate complex and powerful queries. Ideally, an RDF query language should be at least as expressive as relational algebra, making it "relationally complete." However, the expressiveness is often constrained to ensure properties like safety and efficient query optimization.
- **Closure**
    - The closure property ensures that the results of queries are still elements of the RDF data model. For example, if a query operates on an RDF graph, the query results must also be represented as graphs.
- **Adequacy**
    - A language is adequate if it fully utilizes all aspects of the underlying RDF data model. While closure ensures query results stay within the model, adequacy ensures that the entire data model is accessible for querying.
- **Orthogonality**
    - Orthogonality means that all operations in the query language can be used independently of the context in which they are applied. This promotes flexibility and composability in queries.

- **Safety**
    - Safety ensures that any syntactically correct query produces a finite set of results when executed on a finite dataset. This property prevents issues caused by recursion, negation, or certain built-in functions that might otherwise lead to infinite or undefined results.

4.3. SPARQL: The W3C Standard for RDF Querying

The **SPARQL Protocol and RDF Query Language (SPARQL)** is the W3C-recommended standard for querying RDF data. SPARQL supports four main types of queries:

- **SELECT Queries**
    - Similar to SQL, SELECT queries retrieve tabular data based on specified criteria. They include:
        1. **PREFIX**: Defines XML namespaces associated with prefixes for easier referencing.
        2. **SELECT Clause**: Specifies the data to be returned.
        3. **WHERE Clause**: Filters the data based on conditions.
- **ASK Queries**
    - ASK queries return a simple "YES" or "NO" response, indicating whether the specified data exists in the dataset. These queries are particularly useful for interacting with newly discovered web services, as they can quickly determine if a service meets the required criteria.
- **DESCRIBE Queries**
    - These queries return RDF data describing resources relevant to the query. The query engine determines which data to include, making DESCRIBE queries useful for exploratory tasks.
- **CONSTRUCT Queries**
    - CONSTRUCT queries create new RDF graphs based on the query criteria, allowing developers to define the structure and content of the output graph.

4.4. Advantages of SPARQL

SPARQL provides several benefits tailored to RDF data and Semantic Web applications:

- **RDF/XML Compatibility**: Both DESCRIBE and CONSTRUCT queries output results in RDF/XML format, facilitating further RDF-based processing.
- **SPARQL XML Results**: This standardized XML format for SPARQL results simplifies integration with XML tools like XSLT, allowing for easy transformation and processing.
- **Efficient Web Service Interaction**: ASK queries are lightweight and ideal for quickly assessing the relevance of web services, reducing overhead compared to SELECT queries.
- **Tabular Results**: Like SQL, SPARQL SELECT queries return data in a tabular format, making it straightforward to process and transform results programmatically.

4.5. Reasoning and Data Types in RDF Queries

RDF's formal semantics support entailment, enabling RDF query languages to infer implicit data. Queries may distinguish between explicitly stated data and inferred data, enriching the querying capabilities.

Additionally, RDF supports **XML Schema data types**, which can define and validate data values. This compatibility allows RDF query languages to handle a wide range of data formats and incorporate custom data types defined using XML Schema's extensibility framework.

4.6. Tolerance for Incomplete or Contradictory Data

In real-world scenarios, RDF datasets often lack complete information or may contain inconsistencies. A robust RDF query language must accommodate such imperfections, ensuring reliable results even when the data is incomplete or contradictory.

4.7. Final thoughts on SPARQL and RDF Querying

SPARQL has established itself as the standard RDF query language due to its flexibility, compatibility with XML, and robust querying capabilities. Its ability to handle RDF graphs, support entailment, and provide efficient query mechanisms makes it indispensable for Semantic Web applications. With SPARQL, developers can seamlessly query RDF data, transform results, and interact with services in a standardized, scalable manner.

5. Conclusions

Although the Semantic Web is still very much in development, its potential future impact is both significant and promising. The core advantage of the Semantic Web lies in its ability to enable computers to "understand" and process the vast and complex array of information available online, transforming the way we interact with and utilize the Web. For example, rather than manually searching through multiple sources, a computer could instantly locate the nearest Chinese restaurant and reserve a table based on specific user preferences, making tasks more efficient and personalized.

At the heart of the Semantic Web are Web services, which play a pivotal role in its functionality. These services, alongside foundational technologies such as RDF (Resource Description Framework) and OWL (Web Ontology Language), form the backbone of the Semantic Web's architecture. RDF provides a framework for describing relationships between data, while OWL enables the creation and sharing of detailed ontologies, helping define the meaning and context of information.

By leveraging these standards and employing familiar programming languages for message exchange, Web services contribute to the seamless integration and interaction of diverse data sources and systems. This synergy is expected to drive the evolution of the Semantic Web, making it a powerful tool for retrieving precise and relevant information tailored to individual needs.

In the years ahead, as the Semantic Web continues to mature, it holds the promise of revolutionizing how we access, understand, and utilize digital information—moving beyond traditional keyword-based searches to a more intelligent and intuitive web experience.

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ETHICS OF USING AI FOR ACADEMIC RESEARCH AND PLAGIARISM

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Abstract

This study article aims to increase awareness regarding the utilization of Artificial Intelligence (AI) in academic work and its resulting influence on the issue of plagiarism. The study seeks to provide insight into the existing patterns and methods of using AI in academia by analyzing data from a wide range of students. The purpose of this work is to make a substantial contribution to the continuing discussion on the role and impact of AI, highlighting the need for careful consideration and ethical guidelines to navigate the complex landscape of AI-assisted academic endeavors.

Keywords: Artificial Intelligence, academic, plagiarism, ethics, guidelines

JEL Classification: C61

1. Introduction

The evolution of mankind has always been facilitated by discoveries and innovation. The invention of the wheel, in the 4th millennium BC, the discovery of electricity by William Gilbert in 1600, and the invention of the telephone by Alexander Graham Bell in 1875, all

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form the basis on which humankind has developed and paved the way for discoveries and groundbreaking inventions, the latest one having the potential to change the world as we know it: Artificial Intelligence.

Artificial Intelligence (AI) is known as the simulation of human intelligence in robots that are built to function and think like humans. Artificial Intelligence can make decisions, learn from mistakes, and carry out operations that normally call for human intelligence [1].

The undeniable impact of Artificial Intelligence on our lives is clear. AI methodologies such as machine learning, deep learning, and artificial neural networks are revolutionizing the way data is being processed and analyzed. Furthermore, autonomous and semi-autonomous systems are experiencing growing use across several industries, including healthcare [2], transportation [3], and production [4].

Various tools based on Artificial Intelligence help programmers write more efficient and clean code [5][6], help bloggers write more intriguing, attractive, and complex articles [7], and even generate new innovative ideas, which can help people start new businesses or lead them to discoveries [8]. Artificial Intelligence can enhance the learning experience by analyzing individuals' weaknesses, strengths, and learning styles to tailor a customized strategy, ultimately improving the overall learning outcome.

But with great power comes great responsibility. The principles and notions that should guide the advancement and use of Artificial Intelligence have caused extensive debate due to its powerful transformative impact and substantial influence in various societal domains. Recent scientific research and media coverage has primarily focused on the concerns of AI's capacity to eliminate human employment [9], be exploited by malicious individuals, avoid responsibility, and unintentionally propagate bias, thus compromising justice [10].

Academia is a significant arena for exploring the accomplishments and difficulties linked with Artificial Intelligence (AI), building on the basis outlined above. The incorporation of AI in academic environments involves not only an expansion of its technological capacities but also an examination of its ethical and societal consequences.

The potential of AI to customize educational experiences [11] is significant. AI can personalize educational content based on the distinct learning patterns of each student, thereby adapting to their own requirements and strengths. This has the potential to result in enhanced learning outcomes and a transformative shift in educational practices.

AI technologies possess the capacity to efficiently process extensive quantities of data, beyond the effectiveness of conventional methods [12]. In the context of academic research, this can lead to accelerated and more precise outcomes, empowering researchers to derive profound understandings and conclusions that were previously unreachable due to the complex nature or magnitude of the data.

Plagiarism and academic integrity [13] are a highly debated issue in the field of AI in academia. Artificial intelligence tools, such as sophisticated writing aids, can help create work that blurs the boundaries of authorship. This prompts worries regarding the authenticity and ethical utilization of AI-generated information in academic endeavors.

2. Prior Research

The use of AI tools such as ChatGPT by students and the impact this technology has is a topic of great interest, especially in the scientific community. There are already a large number of articles [14] that highlight the fact that Large Language Models and other AI-powered tools could be both a blessing and a curse for humanity. While using these mechanisms helps when it comes to productivity, many are concerned that overreliance on these tools might have a drastic effect on the critical thinking of those who use them. After the New York City Public Schools decided to ban the use of ChatGPT by its students, a spokesperson stated that: "While the tool may be able to provide quick and easy answers to questions, it does not build critical-thinking and problem-solving skills, which are essential for academic and lifelong success"

One article that focuses on the limitations of ChatGPT and its impact on academia and libraries [15] states that "One of the main limitations is that GPT models are based on a statistical approach that learns patterns from a large data set of text, which can perpetuate biases and stereotypes present in the data. This means that the model may generate offensive or harmful output. Additionally, GPT models are not able to fully understand the context and meaning of the text they generate and they are not able to perform well in tasks that require common sense reasoning or logical reasoning which is not covered in the training data". This article concludes that while the benefits of using AI are notable and desirable by students, ethical considerations such as privacy and bias have to be taken into account: "ChatGPT has considerable power to advance academia and librarianship in both anxiety-provoking and exciting new ways".

Another article [16] focused on the role of Artificial Intelligence in academic writing, and the authors believe that when it comes to scientific writing, ethical concerns could limit the use of AI tools such as chatbots. Humans incorporate what they have learned from others as well as their own ideas in the process of creating new articles. Individuals are therefore prone to repeating the conclusions, statements, and written works of others, and thus come dangerously close to committing plagiarism by presenting an idea without properly citing the original writers.

AI or ChatGPT systems can commit plagiarism under this definition but can also be programmed to avoid copying others by rephrasing their work like what human authors do. However, using programs to reformulate sentences and writing to reduce the percentage of plagiarism (i.e., asking the software to rewrite a section written by other authors with

different words) could not be considered acceptable in scientific research. If we define "plagiarism" as a mere act to copy someone else's work, just rephrasing what was written, regardless of the method used, and without adding anything personal, it is a violation of academic integrity. For this reason, journal editors should use programs to detect written content using AI to detect plagiarism better.

Moreover, the lack of an expert and critical human mind behind scientific work (which is the basis of the scientific method) could lead to a risk of perpetuating or amplifying existing biases and inaccuracies in the data, providing unfair results and hampering scientific growth.

A recent study [16] regarding journal editors' beliefs about the ethicality of using ChatGPT/AI tools for publishing concluded that AI tools are acceptable under specific circumstances. After conducting a series of surveys, they identified the fact that tasks such as summary writing, writing computer code, and editing text using AI tools are mostly considered acceptable. Any tools that are particularly useful for analyzing or processing data or aiding in the final writing/editing stages of the research process are regarded as suitable, but the editors also highlight the importance of disclosing AI use as is customary for any methodological procedure or tool.

3. Conducting the Survey

The method used to collect data for this study was through a survey, which was distributed mostly to computer science students from various institutions but also to high school students and people who work in the field of IT. This approach ensures a broad range of responses and perceptions on the addressed subject. This work aimed to gather diverse and comprehensive insights, reflecting the varied experiences of participants concerning the topic under study. By doing so, we were able to capture a wide spectrum of views and opinions, highlighting the distinct experiences of the participants within the context of the theme addressed.

A response system consisting of only "Not at all, Rarely, Sometimes, Often, Always" was used. It represents a Likert scale [17] which is highly valued in surveys for its ability to reliably measure unobservable constructs and its flexibility in response options, ensuring high internal consistency and adaptability across various research contexts. Continuous advancements in its development have further enhanced its accuracy and utility in modern research.

The survey consisted of a series of questions that were categorized into three distinct segments, each focusing on certain elements.

The objective of the initial segment (Demographics and Familiarization with AI) is to collect demographic data and evaluate the respondents' level of acquaintance with Artificial

Intelligence (AI). Contextualizing the responses within the particular educational and age demographics, the study takes into account the age group, academic year, and kind of institution. Furthermore, evaluating the level of familiarity with AI helps in comprehending the existing knowledge and comfort of responders with AI technology. Understanding their perceptions and interactions with AI in an academic setting is of the highest importance.

The objective of the second section is to examine and evaluate the utilization and consequences of Artificial Intelligence in the field of research. This section attempts to comprehend the scope and method by which AI tools are included in academic practices. The objective is to find out the frequency and categories of AI tools used in academic research and activities. The survey seeks to get insights into the practical implementation of AI in academia by asking about the frequency of AI tool usage for different academic goals, such as data analysis, and its impact on research efficiency. In addition, this section examines the level of knowledge regarding ethical concerns such as plagiarism when utilizing AI-generated content. This helps to gain a more comprehensive picture of the responsible use of AI in academic work.

The third section is specifically focused on examining the ethical implications and awareness related to the utilization of AI in educational environments. It evaluates the frequency at which ethical considerations about the usage of AI, specifically in the instance of ChatGPT, are taken into account, and the extent to which these ethical problems are discussed in academic contexts. This section explores individuals' perspectives regarding the influence of AI on academic writing abilities, as well as their level of trust in the accuracy and reliability of AI-generated content for academic use. The objective is to evaluate the level of ethical awareness and comprehension regarding the possible consequences and constraints of AI in academic research.

Each of these topics is essential for obtaining an in-depth understanding of the use, influence, and ethical implications of AI in academic environments. The collected responses will help in identifying gaps in knowledge, possible domains for more training, and strategies to encourage responsible and ethical utilization of AI in academia.

4. Results and Analysis

We will now examine the gathered data, seeking noteworthy patterns, interesting correlations, and any other relevant concerns. We will also attempt to analyze and make sense of this data within the wider context of ethical considerations surrounding the utilization of artificial intelligence in academic research.

During this study, we obtained a significant level of participation, shown by the active involvement of 101 individuals who offered their answers to the questionnaire.

A majority of 43,5% of the respondents self-identified as "Beginners" in the field of Artificial Intelligence. This indicates that although they are Computer Science students, a significant number do not consider themselves advanced in AI knowledge.

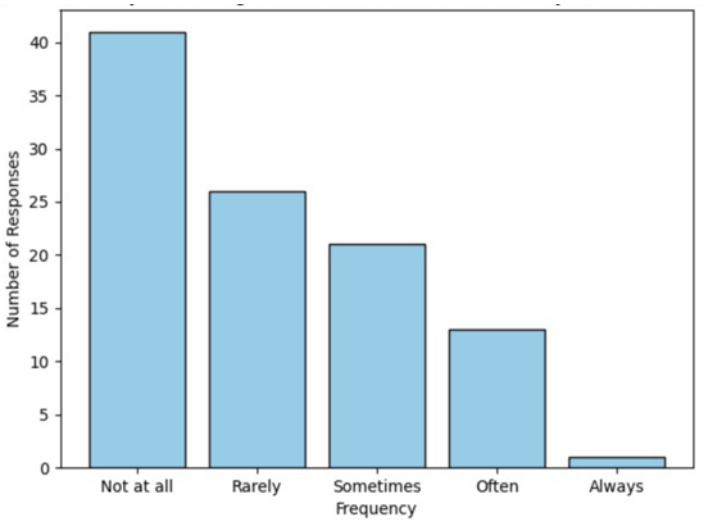

Figure 1. When using AI-generated information or content, how often do you cite it as a source in your academic work?

As shown in Figure 1, a significant proportion of respondents (41 out of 101) indicated that they do not cite AI-generated information or content at all in their academic work. This response suggests a potential risk area for plagiarism or a lack of clarity regarding academic rules for citing AI-generated sources.

Regarding the question, "How often do you consider the ethical implications of using ChatGPT in your academic work?", the responses showed a relatively even distribution across various levels of concern. Notably, "Sometimes" emerged as the most common response, with 34 out of 101 respondents selecting it. This outcome indicates a varying degree of awareness among individuals about the risks and ethical considerations associated with the use of AI, like ChatGPT, in academic research contexts.

In response to the question, "How often do you consult your institution's policies on the use of AI in academic research?", it was found that a significant majority, constituting 33.66% of respondents, do not consult their institution's policies at all. This suggests a scenario where there is either a low level of awareness about these policies among researchers or a lack of concern for adhering to formal guidelines when utilizing AI in academic research.

Addressing the query, "How often do you use AI tools to analyze or interpret data in your research?", the gathered data reveals a notably high frequency of AI tool usage among

respondents. Specifically, 32.67% reported using AI tools often in their academic endeavors, while 31.68% indicated they use them sometimes. This pattern suggests that AI tools are a significant component in the academic activities of the respondents, encompassing a range of tasks from research to other academic-related functions.

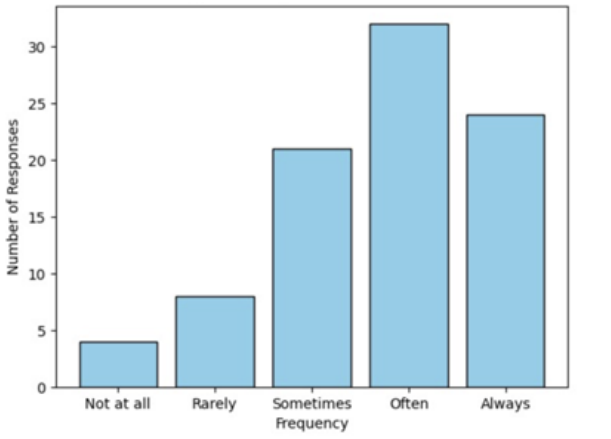

Figure 2. How often does using AI make your research process more efficient?

Figure 2 highlights a significant insight regarding the perceived efficiency of using AI tools among respondents. Specifically, 26% of them consider themselves to be always more efficient when utilizing AI tools, and a further 36% believe they are often more efficient with these tools. This data suggests that a majority of the respondents perceive a notable increase in their work efficiency when incorporating AI tools into their tasks, emphasizing the need for awareness about the various implications associated with the use of such technology in their work.

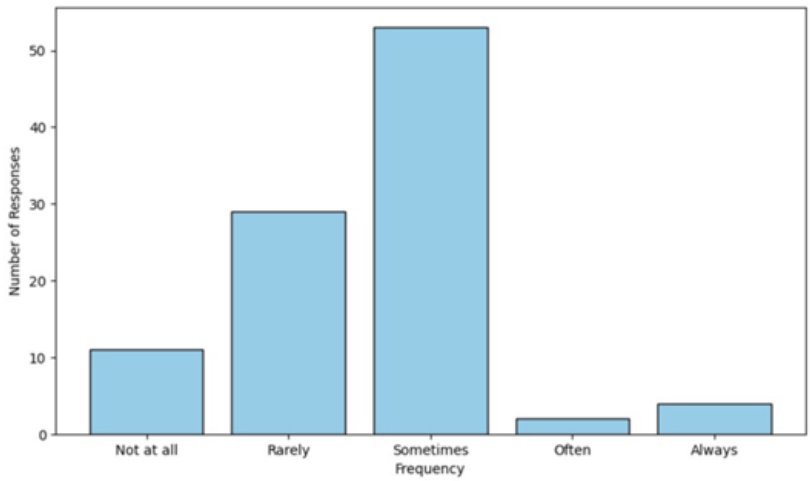

Figure 3. How often do you feel confident in the accuracy and reliability of content generated by AI language models for academic purposes?

Figure 3 shows that 46% of respondents sometimes feel confident in the accuracy of the content generated by AI language models for academic purposes, while 29% are rarely confident and 7% have no confidence at all. This finding is particularly concerning, especially when considered in conjunction with the results from the previous question. The juxtaposition of the majority of respondents using AI tools and believing in their efficiency, against the backdrop of having little to no trust in the content produced by these tools, suggests a possible over-reliance on using these AI tools without adequate trust in their output.

As highlighted in the survey question about awareness of plagiarism issues when using AI-generated content in academic work, most respondents acknowledge this problem. Specifically, 36% are always aware, and 33% are often aware of plagiarism concerns. However, it's noteworthy that 31% of respondents still lack awareness of the issues associated with using AI-generated content in academic contexts. This indicates a need for more focused educational efforts to enhance understanding among students and academics in this area.

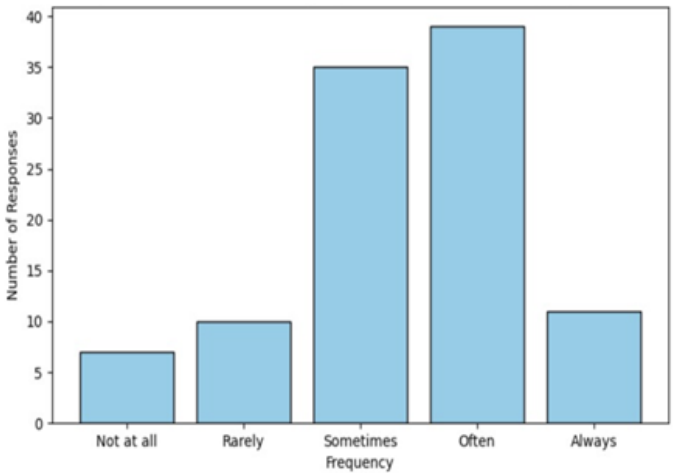

Figure 4. Do you think using AI language models to the quality of academic research?

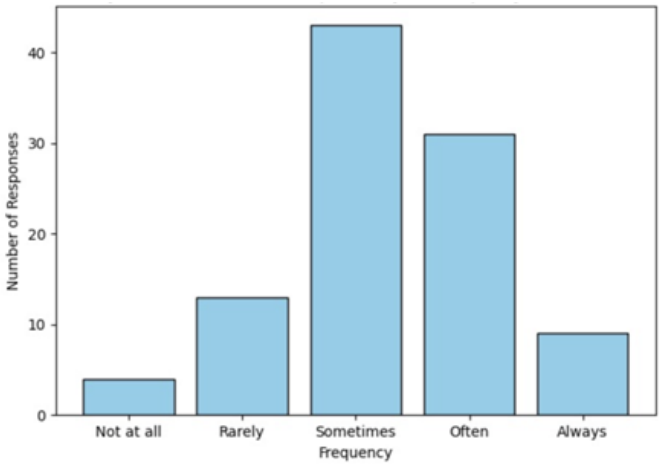

Figure 5. Do you think AI contributes positively contributes to academic plagiarism?

Figure 4 presents the responses to the question regarding the contribution of AI language models to academic plagiarism. The majority of respondents, 40 out of 101, believe that the use of AI language models often leads to academic plagiarism. This suggests a heightened awareness among students about the potential of AI language models to produce content that could be misused for academic plagiarism.

Figure 5 addresses the question of AI's positive contribution to the quality of academic research. A considerable number of students, 32 out of 101, responded that AI often enhances the quality of academic research positively. This response demonstrates that students recognize the advantages AI can offer in academic settings. However, when

considered alongside the responses from the previous question, it seems that students may be overlooking the ethical challenges in favor of the positive outcomes. This dichotomy emphasizes the importance of educating students about the ethical use of AI in academic research.

Regarding the question, "Do you discuss with colleagues the ethical use of AI language models in academic research?", the majority of respondents, comprising 48 out of 100, indicated that they rarely or never engage in discussions about the ethical use of AI language models in academic research. This points to a notable lack of interest or awareness among a significant portion of the students concerning the ethical implications of utilizing AI in academic settings. It suggests that other aspects, such as workload or achieving academic goals, are given higher priority, overshadowing the importance of understanding and addressing the ethical dimensions of AI use in academic research.

5. Conclusions

The survey findings reveal a critical need for increased awareness, education, and discussion surrounding the ethical utilization of artificial intelligence in academic settings, specifically with the appropriate referencing of AI sources and the avoidance of plagiarism. Furthermore, it emphasizes the necessity of establishing a balance between embracing AI technology and maintaining strict academic standards, specifically regarding promoting research and critical thinking abilities. Educational institutions need to establish explicit protocols and encourage transparent dialogue regarding the ethical and moral utilization of AI. This will guarantee that technology is employed in a manner that enhances academic integrity rather than compromising it.

Ultimately, the information collected indicates an increasing recognition of the ethical dilemmas and potential dangers of plagiarism linked to the utilization of artificial intelligence in academic research. Nevertheless, there is a lot of potential to further improve the education and guidance provided to students and researchers regarding optimal practices in this field. This emphasizes the need to incorporate AI ethics into the academic curriculum and the necessity for clearly defined norms for the conscientious utilization of AI technologies in education.

Appendix

Except for the first 5 questions, the mean and standard deviation are calculated by attributing a value in the range [1, 5] for each answer: Not at all = 1, Rarely = 2, Sometimes = 3, Often = 4, Always = 5.

Question	Mean	Standard Deviation
What age group do you fall into?	21.48 (years)	2.63 (years)
What year of study are you currently in?	3.09	1.35
What type of higher education institution are you studying at?	Public University	-
How familiar are you with Artificial Intelligence (AI) fields?	Intermediate to Beginner	-
What AI tools do you use?	ChatGPT	-
When using information or content generated by AI, how often do you cite it as a source in your academic work?	2.29	1.06
How often do you use AI tools in your academic activities?	2.4	1.26
How often do you consider the ethical implications of using ChatGPT in your academic work?	2.4	1.16
How often do you think the use of AI for academic research undermines the learning process?	2.14	1.02
How often do you consult your institution's policies regarding the use of AI in academic research?	2.31	1.13
How often does the use of AI make your research process more efficient?	3.07	1.23
How often is the topic of AI ethics and its use in academic research discussed in your academic environment?	2.37	1.02

Question	Mean	Standard Deviation
How often do you feel you fully understand the capabilities and limitations of AI language models in the context of academic research?	2.41	1.12
How often do you use AI tools for data analysis or interpretation in your research?	2.17	1.05
How often do you believe that reliance on AI language models impacts the academic writing skills of students or researchers?	2.52	1.05
How often do you feel confident in the accuracy and reliability of content generated by AI language models for academic purposes?	2.24	1.06
How often are you aware of plagiarism issues when using content generated by AI tools in academic work?	2.64	1.17
How frequently do you believe that the use of AI language models contributes to plagiarism in the academic environment?	2.13	1.01
How frequently do you believe AI positively contributes to the quality of academic research?	2.13	1.02
How frequently do you find yourself relying on AI tools to complete academic or research tasks?	2.21	1.06
How frequently do you believe that the use of AI language models affects the development of critical thinking skills in the academic environment?	2.2	1.01
How frequently do you discuss with colleagues the ethical use of AI language models in academic research?	2.31	1.06

Question	Mean	Standard Deviation
How frequently has your approach to conducting academic research changed due to the availability of AI tools?	2.23	1.02
How frequently are you concerned about the potential misuse of AI language models in academic research?	2.15	1.04

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IMPROVING STATIC AND DYNAMIC LOAD CAPACITIES OF HYBRID CERAMIC BALL BEARINGS IN WIND GENERATORS WITH ARTIFICIAL INTELLIGENCE-DRIVEN DESIGN STRATEGIES

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Somenath BHATTACHARYA[2]

Abstract

This research introduces a novel AI-driven optimization technique to enhance hybrid ceramic ball bearings in wind turbine generators. It focuses on improving both static and dynamic load capacities to address the challenges posed by harsh operating conditions. By utilizing a unique dynamic approach for assigning probabilities in the crossover and mutation processes of a genetic algorithm, significant improvements were achieved. The study recorded an 11.90% increase in dynamic load capacity and an 11.25% boost in static load capacity. These enhancements are critical for reducing failure risks and ensuring the reliability of bearings under high-stress conditions. Wind turbines operate in demanding environments, making durable and efficient components essential for long-term functionality. Improved bearing performance contributes directly to the robustness and reliability of wind energy systems. This advancement not only strengthens bearing technology but also supports more efficient wind power generation. Enhancing the durability of wind turbines can lead to more cost-effective and sustainable renewable energy solutions. Ultimately, this research sets new standards for both bearing design and renewable energy optimization.

Keywords: AI-driven Optimization, Bearing Reliability, Dynamic Load Capacity, Genetic Algorithm, Hybrid Ceramic Ball Bearings, Renewable Energy Systems, Static Load Capacity, Wind Turbine Optimization

JEL Classification: N7

1. Introduction

Global weather patterns and ecosystems are being progressively impacted by climate change, driven by the unrelenting rise in greenhouse gas emissions. This growing environmental threat has spurred the urgent need for alternative, cleaner energy sources,

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with wind energy emerging as a pivotal solution. Unlike fossil fuels, wind power generates electricity without emitting carbon dioxide, making it a vital tool in the battle against global warming. The scalability and versatility of wind energy systems—from offshore installations to small-scale wind farms—further enhance its potential to mitigate the harmful effects of climate change across diverse regions.

Over the past decade, the capacity of wind energy worldwide has surged, reflecting its critical role in the global energy transition. In 2013, global installations stood at 539 gigawatts (GW); by the end of 2023, this figure is expected to reach approximately 918 GW, marking an impressive annual growth rate of 5.2%. This rapid expansion highlights wind energy's increasing competitiveness and technological maturity, with nations around the world ramping up their investments in both onshore and offshore wind projects. With the capability to offset as much as 1.1 billion tons of CO_2 emissions annually, wind power has become indispensable in the quest to meet international climate targets and reduce reliance on non-renewable energy sources [1].

The International Energy Agency's forecast is equally optimistic, projecting that by 2040, wind energy will account for 35% of global power production—up significantly from its current share of around 10%. This trajectory underscores the growing importance of wind power as both an environmental necessity and a driver of economic development. Advances in turbine technology, better grid integration, and supportive policy frameworks are contributing to the continued reduction in costs, making wind energy increasingly accessible and viable in both developed and developing regions.

Furthermore, wind energy's decentralized nature offers resilience against climate-related disruptions, such as the increasingly erratic behaviour of weather systems and the intensification of natural disasters. In addition to reducing emissions, wind power diversifies the energy mix, stabilizing power grids and boosting energy security. As research and development, continue to optimize wind turbine designs and enhance efficiency, wind energy's role will only grow more vital in forging a sustainable, low-carbon future [2].

The total effectiveness, dependability, and lifespan of wind turbine generators are critically dependent on the design and performance of their bearings. Bearings are fundamental components that not only manage mechanical loads but also ensure the smooth rotation of the generator's moving parts by minimizing friction. Given the significant stresses that wind turbine systems face—such as fluctuating wind speeds, variable mechanical loads, extreme temperatures, and harsh environmental conditions—the importance of robust and well-designed bearings cannot be overstated. In particular, wind turbine bearings must be designed to handle both axial and radial loads with high efficiency and durability, as even minor performance inefficiencies can result in significant energy losses, downtime, and increased operational costs over time.

The hostile operating environment of wind turbines necessitates bearings that can endure immense pressures, vibrations, and wear without frequent maintenance or failure. In addition, wind turbines are expected to operate continuously for decades, meaning the durability and reliability of the bearings are paramount for ensuring the long-term sustainability of the system. If bearings fail prematurely due to wear, inadequate lubrication, or poor load distribution, the resulting downtime can lead to costly repairs and lost energy

production. Therefore, advancements in bearing technology are essential not just for maintaining optimal performance but also for enhancing the economic viability of wind energy by reducing the risk of unexpected failures and extending the overall lifespan of turbine components [3].

Recent innovations in bearing materials have played a transformative role in improving the durability and performance of wind turbine generators. Hybrid ceramic bearings, in particular, have emerged as a popular choice due to their superior resistance to wear and their ability to operate under extreme environmental conditions. These bearings utilize ceramic rolling elements combined with traditional steel races, offering several advantages over conventional steel bearings. The ceramic components are lighter, more wear-resistant, and capable of withstanding higher temperatures, which makes them ideal for applications in high-stress environments like wind turbines. The adoption of hybrid ceramic bearings reduces the risk of fatigue, cracking, and spalling, which are common issues in traditional steel bearings, especially under high-load conditions. By ensuring that the bearings can operate efficiently under such demanding conditions, hybrid ceramics not only enhance the performance of wind turbines but also contribute to their overall reliability and sustainability [4].

Another crucial aspect of bearing design in wind turbines is the optimization of lubrication and load distribution. Proper lubrication minimizes friction and wear, preventing surface damage and extending the bearing's operational life. Inadequate lubrication can lead to increased friction, higher temperatures, and accelerated wear, resulting in premature failure. To address these challenges, researchers are focusing on the development of advanced lubricants and lubrication systems that ensure consistent performance even in the most extreme conditions. Similarly, optimizing load distribution within the bearing is key to preventing uneven wear and reducing stress concentrations, which can otherwise lead to localized damage and early failure. Effective load distribution ensures that the bearing's rolling elements and raceways are subjected to uniform stresses, thereby enhancing both performance and durability.

The development of bearings with improved lubrication and load distribution properties directly translates into lower maintenance requirements and a reduced risk of failure. For wind turbine operators, this is critical because it minimizes the need for costly repairs and unplanned downtime, which can have a significant impact on operational efficiency and overall profitability. With bearings that require less frequent maintenance, wind turbine systems can operate more reliably over longer periods, ultimately reducing the total cost of ownership and improving the competitiveness of wind energy as a renewable power source.

The introduction of artificial intelligence (AI) into the field of mechanical design is further revolutionizing the way bearings are developed and optimized. AI-driven tools and methodologies are increasingly being used to enhance the design process by providing more accurate predictions, faster simulations, and deeper insights into bearing performance under a wide range of operating conditions. Through the use of machine learning algorithms, neural networks, and genetic algorithms, AI can analyse vast amounts of data related to bearing behaviour, enabling engineers to identify optimal design configurations with unprecedented precision [5]. For example, AI can model the effects of different materials, geometries, and lubrication strategies on bearing performance, allowing engineers to

evaluate the trade-offs between various design parameters and choose the most efficient solutions.

One of the most significant advantages of AI in bearing design is its ability to accelerate the development cycle. Traditional bearing design and testing processes often involve multiple iterations of prototyping, testing, and refinement, which can be time-consuming and costly. By using AI to simulate bearing performance in virtual environments, engineers can significantly reduce the need for physical prototypes and testing. AI algorithms can predict how a bearing will behave under different loads, temperatures, and speeds, providing valuable insights that can inform design improvements before a prototype is even built. This not only speeds up the development process but also reduces the overall cost of bringing new bearing technologies to market.

In addition to improving design efficiency, AI also enhances the reliability of wind turbine bearings by enabling more accurate predictions of potential failure modes. By analysing data from real-world turbine operations, AI systems can identify patterns and anomalies that may indicate early signs of bearing wear or failure. This predictive maintenance capability allows operators to address issues before they lead to costly downtime, further improving the dependability of wind energy systems.

As AI continues to evolve, its applications in bearing design will likely become even more sophisticated, leading to the creation of smarter, more resilient components that can better withstand the stresses of high-speed, high-load applications like wind turbine generators. AI-driven optimization of bearing designs is pushing the boundaries of what is achievable in mechanical engineering, allowing for the development of components that are not only more efficient and durable but also more environmentally sustainable. By reducing frictional losses and improving load distribution, these advanced bearings contribute to the overall energy efficiency of wind turbines, helping to maximize the amount of clean, renewable energy that can be generated from wind resources.

Ultimately, the integration of AI in bearing design and the ongoing development of innovative materials and lubrication strategies are driving the future of wind energy technology. As wind turbines continue to grow in size and capacity, the demand for more robust and reliable bearing systems will only increase. The synergy between AI and advanced engineering techniques offers a pathway to smarter, more durable wind turbine components, ensuring that wind energy remains a key pillar of the global transition to a sustainable, low-carbon future [6].

This study delves into the optimization of hybrid ceramic ball bearings for wind turbines by enhancing a genetic algorithm with an innovative dynamic function that adjusts crossover and mutation probabilities in real-time. Traditional optimization methods often struggle to navigate the complex, multi-dimensional design space of bearing performance, particularly under the varying operational conditions that wind turbines experience—such as fluctuating wind speeds, load patterns, and environmental stresses. These conventional approaches tend to rely on static parameters, which can limit their ability to find the most efficient design solutions, especially when dealing with the inherent trade-offs between factors like load capacity, frictional losses, and material durability.

In contrast, the proposed dynamic adjustment mechanism within the genetic algorithm enables a more nuanced and adaptive exploration of the design space. By continuously modifying the crossover and mutation rates based on the progress of the optimization process, the algorithm is able to maintain a better balance between exploration (searching for new, diverse solutions) and exploitation (refining existing solutions). This adaptive approach allows the genetic algorithm to avoid premature convergence—a common issue in traditional algorithms where the search becomes stuck in suboptimal regions of the design space. As a result, the dynamic genetic algorithm is better equipped to converge on truly optimal bearing designs, which significantly boosts both performance and efficiency.

A key outcome of this research is the marked improvement in both static and dynamic load capacities of the optimized hybrid ceramic ball bearings. These improvements are not merely incremental but substantial enough to have a profound impact on the overall reliability and lifespan of wind turbine bearings, especially when operating in harsh and unpredictable environments. Wind turbines are frequently exposed to extreme conditions, including temperature variations, moisture, high wind speeds, and varying loads, all of which place significant stress on the bearings. The enhanced load capacities allow the bearings to better withstand these challenges, reducing the likelihood of fatigue, wear, and failure over time. This directly translates to lower maintenance costs, reduced downtime, and longer operational lifespans for wind turbines, making wind energy generation more cost-effective and sustainable.

Moreover, this dynamic optimization technique sets new benchmarks in the field of bearing design by addressing critical performance metrics that are often difficult to optimize simultaneously. Traditionally, improvements in one area of bearing performance, such as increased load capacity, might come at the expense of other important factors like friction reduction or wear resistance. However, the proposed approach demonstrates that it is possible to achieve significant gains across multiple performance metrics without sacrificing one for another. This balance is particularly important in renewable energy systems, where maximizing efficiency and durability is essential for ensuring the long-term viability of wind power as a sustainable energy source.

In addition to its direct benefits for bearing design, the study's use of dynamic genetic algorithms opens up broader possibilities for optimizing other key components of renewable energy systems. For example, the same adaptive methodology could be applied to the design of wind turbine blades, gearboxes, or even the entire turbine structure, where similar challenges of balancing multiple performance criteria exist. By pushing the boundaries of what can be achieved in component optimization, this research contributes to the overall advancement of wind energy technology, driving improvements in efficiency, sustainability, and cost-effectiveness.

Furthermore, the successful application of artificial intelligence techniques, such as genetic algorithms, to complex engineering problems highlights the growing role of AI in shaping the future of renewable energy. As the energy sector continues to shift toward more sustainable solutions, the integration of AI-driven optimization methods will become increasingly critical in meeting the demand for higher performance, lower costs, and

reduced environmental impact. This study serves as a model for how AI can be leveraged to solve intricate design challenges, offering a path forward for the development of more reliable, efficient, and durable wind turbine systems. By enhancing a genetic algorithm with a dynamic function for adjusting crossover and mutation probabilities, the study not only achieves impressive improvements in bearing performance but also sets the stage for further advancements in wind turbine design and other renewable energy components. These findings underscore the importance of continued research and development in this field, with the potential to revolutionize the way critical components of wind power systems are designed, thereby boosting the sustainability and efficiency of global wind energy production.

2. Objective Formulation

In any optimization research, a robust objective formulation is fundamental to defining the constraints and goals that will direct the entire process. This stage is crucial, as it transforms complex, real-world problems into quantifiable objectives that an optimization algorithm can systematically address. A well-defined objective formulation is not merely a procedural requirement but serves as the conceptual framework guiding the search for optimal solutions. It allows the inherent complexity of the problem to be distilled into measurable parameters, thus facilitating a structured and methodical approach to optimization.

The objective formulation must go beyond merely stating the desired outcomes—such as cost minimization, productivity enhancement, or performance improvement. It also needs to incorporate the necessary constraints and trade-offs that characterize real-world applications. These constraints, which may include factors such as budgetary limitations, resource availability, regulatory compliance, or technical limitations, are integral to the formulation process. Ignoring these constraints can lead to solutions that are theoretically optimal but practically infeasible. Therefore, an effective objective formulation must reflect a comprehensive understanding of the system's operational environment, ensuring that the optimization process yields solutions that are both realistic and applicable.

A key aspect of this formulation is the need to explicitly account for trade-offs between conflicting objectives. In many real-world scenarios, optimizing one objective may necessitate concessions in another. For instance, in engineering design, objectives such as maximizing material efficiency, improving durability, or minimizing energy consumption may conflict with each other. Enhancing material utilization might reduce costs, but could also compromise the structural integrity or lifespan of the component. Similarly, reducing energy consumption may require advanced technologies that increase overall system complexity and cost. A well-crafted objective formulation must carefully balance these trade-offs, ensuring that the optimization process remains focused and efficient while addressing the multi-faceted nature of the problem.

The challenge becomes particularly acute in multi-objective optimization problems, where multiple, often conflicting goals must be optimized simultaneously. In such cases, the objective formulation must reflect the relative importance of each goal, often requiring the use of weighting schemes or Pareto-based approaches to navigate the trade-offs between competing objectives. For example, in the optimization of wind turbine systems, objectives

might include maximizing power output while minimizing operational noise and maintenance costs. The optimization algorithm must navigate these competing priorities, seeking a solution that offers an acceptable compromise across all objectives. A robust objective formulation ensures that the optimization process can effectively handle these complexities, providing solutions that are not only mathematically optimal but also practically viable.

Moreover, objective formulation must consider the dynamic and evolving nature of optimization research. As new data becomes available or as the problem context changes, the goals and constraints may need to be redefined or refined. This adaptability is particularly relevant in iterative optimization processes, where preliminary solutions are evaluated and refined over successive iterations. A flexible, well-structured objective formulation allows for this iterative refinement, ensuring that the optimization process remains aligned with both the overarching goals and the evolving realities of the system being optimized.

The efficacy of the optimization process is, to a large extent, contingent upon the clarity and precision of the objective formulation. A well-defined objective reduces the search space, allowing the optimization algorithm to focus on relevant areas and converge more rapidly on optimal or near-optimal solutions. Conversely, a poorly articulated or overly broad objective can lead to inefficient exploration of the solution space, resulting in unnecessary computational overhead and suboptimal results. Therefore, particular attention must be given to the formulation of objectives, with a focus on delineating clear, measurable goals that take into account all relevant variables, constraints, and trade-offs.

In the context of engineering and other applied fields, objective formulation plays a critical role in ensuring that optimization processes address the real-world complexities of system design and operation. For instance, in optimizing the design of mechanical components, such as bearings or turbines, objectives may include enhancing load capacity, reducing frictional losses, or improving durability under operational stresses. Each of these objectives must be carefully formulated to ensure that the optimization process targets feasible design configurations that improve overall system performance while adhering to practical limitations such as cost, manufacturing constraints, and long-term sustainability.

Objective formulation is a foundational element of any optimization research, providing the structured framework necessary for the systematic pursuit of optimal solutions. By translating real-world challenges into measurable goals, and by incorporating necessary constraints and trade-offs, a well-defined objective formulation ensures that the optimization process is both targeted and efficient. Moreover, the iterative nature of most optimization processes necessitates flexibility in objective formulation, allowing for continuous refinement as new data and insights emerge. As such, this critical stage not only guides the optimization process but also serves as a crucial determinant of its success, influencing both the efficiency and practicality of the resulting solutions [7].

2.1 Static Load Enduring Capacity

The static load capacity of a rolling contact bearing is a critical performance metric that determines its ability to support significant loads without undergoing permanent deformation or catastrophic failure. This is particularly important in applications where the bearing operates under low speeds, during idle periods, or experiences heavy loads, such as in wind turbine generators, heavy industrial machinery, or large-scale transportation systems. The static load capacity represents the maximum load a bearing can withstand before plastic deformation occurs, which can permanently alter the geometry of its raceways and rolling elements. Once this deformation threshold is crossed, the bearing's performance is severely compromised, leading to increased friction, vibration, and ultimately, early failure.

Several factors influence the static load capacity of a bearing, each of which plays a critical role in determining the bearing's overall performance and longevity. Material characteristics are perhaps the most fundamental of these factors. Bearings made from high-grade materials, such as hybrid ceramics or advanced steel alloys, are more resistant to deformation under high static loads compared to traditional materials. Hybrid ceramic bearings, for example, possess superior hardness and wear resistance, allowing them to maintain their shape and structural integrity under extreme conditions. These materials also offer enhanced thermal stability, which is particularly beneficial in applications where temperature fluctuations could lead to thermal expansion, further impacting the load distribution within the bearing.

The design of the rolling elements is another crucial factor that directly affects the static load capacity. Rolling elements come in various shapes, including balls, cylinders, or tapered rollers, each offering different load distribution properties. Spherical ball bearings, for example, are more suited for supporting moderate loads at high speeds, whereas cylindrical or tapered roller bearings are designed to handle heavier loads due to their larger contact area with the raceways. The geometry of the rolling elements, including their diameter, length, and surface curvature, must be carefully optimized to ensure maximum contact without excessive stress concentration, which could lead to early material fatigue or failure under static loads.

Surface quality also plays a significant role in determining a bearing's static load capacity. Bearings with finely polished raceways and rolling elements exhibit lower friction and smoother load distribution, reducing the risk of localized stress points that can accelerate wear and deformation. High-quality surface finishes reduce micro-irregularities, which can serve as nucleation sites for cracks or other forms of damage under static loads. Furthermore, advanced surface treatments, such as coatings or surface hardening techniques, can enhance the bearing's resistance to wear, corrosion, and deformation, extending its operational lifespan even under challenging conditions.

In addition to material and design considerations, lubrication is another factor that indirectly impacts static load capacity. While lubrication is more commonly associated with dynamic performance, it also plays a crucial role in preventing excessive friction and wear when the bearing is under static load. Proper lubrication ensures a thin film between the rolling elements and raceways, reducing metal-to-metal contact, which in turn mitigates the risk of

surface damage and deformation under high loads. In applications such as wind turbines, where bearings are often subjected to intermittent motion and prolonged periods of inactivity, maintaining proper lubrication is critical to preserving static load capacity and preventing early failure.

An accurate assessment of static load capacity is essential for ensuring the reliability and durability of bearings in demanding applications. In large-scale systems, such as wind turbines or industrial machinery, bearing failure can lead to substantial economic losses due to increased maintenance costs, unexpected downtime, and, in some cases, catastrophic system failure. Wind turbines, in particular, rely heavily on the performance of their bearings to ensure continuous operation, as failures in these components can lead to prolonged downtime, during which energy generation is halted, impacting both revenue and grid reliability.

Advanced methods for assessing static load capacity involve finite element analysis (FEA) and computational simulations that model the interaction between rolling elements and raceways under various load conditions. These simulations allow engineers to predict the deformation behaviour of bearings under static loads with greater accuracy, taking into account factors such as material properties, rolling element design, surface roughness, and lubrication conditions. By incorporating real-world variables into the assessment process, engineers can optimize the bearing design to ensure it meets the specific demands of its intended application.

Incorporating AI and machine learning techniques into the evaluation process further enhances the precision of static load capacity assessments. AI algorithms can analyse vast amounts of data from experimental tests and simulations to identify patterns and correlations that may not be immediately apparent through traditional methods. This allows for more accurate predictions of bearing behaviour under static loads, as well as the identification of optimal material compositions and design configurations that maximize static load capacity while minimizing the risk of deformation.

The development of hybrid ceramic ball bearings and other advanced bearing technologies is also helping to push the boundaries of static load capacity, enabling bearings to withstand even greater loads without compromising performance. These innovations are especially important in the renewable energy sector, where wind turbines are increasingly being deployed in offshore environments that subject bearings to harsh, unpredictable loads. By improving the static load capacity of bearings, engineers can enhance the overall efficiency, reliability, and longevity of wind turbines, contributing to the sustainability of wind power generation and reducing the need for costly maintenance interventions.

The static load capacity of rolling contact bearings is a crucial factor in their performance and longevity, particularly in high-load, low-speed applications like wind turbine generators and industrial machinery. The ability to accurately assess and optimize static load capacity is essential for ensuring the reliability of these components, as failure can lead to significant operational and financial consequences. Advances in material science, design optimization, surface quality, and lubrication, coupled with AI-driven assessments, are driving the

development of bearings that can withstand higher static loads while maintaining their integrity, ultimately contributing to more robust and efficient systems in various industries.

2.2 Dynamic Load Enduring Capacity

The dynamic load endurance capability of a rolling contact bearing is a critical parameter that determines its ability to withstand repetitive stress and maintain its structural integrity and performance over an extended period. Bearings are integral components in various mechanical systems, and their reliability directly impacts the efficiency and longevity of these systems. This capacity is especially crucial in applications that demand continuous or high-speed operation, such as wind turbines, vehicle engines, and industrial machinery, where bearings are subjected to cyclic loads that vary in intensity and frequency.

In such environments, a bearing's ability to endure repeated loading without sustaining damage—such as fatigue cracks, pitting, or spalling—is paramount. Fatigue failure, which results from prolonged exposure to fluctuating loads, can lead to surface deterioration and ultimately compromise the bearing's functionality. The maximum dynamic load that a bearing can support before such fatigue damage occurs is its dynamic load capacity, a key measure of its overall durability and reliability in high-demand applications.

Several factors influence the dynamic load capacity of a bearing, making it essential to consider them during the design and manufacturing process. First, the quality of the lubricant plays a significant role. Lubrication ensures smooth operation by reducing friction and wear between the bearing's rolling elements and raceways. Inadequate or deteriorating lubrication can lead to increased friction, heat generation, and wear, accelerating the onset of fatigue damage. Therefore, choosing a high-performance lubricant and ensuring proper lubrication maintenance is vital to extending bearing life.

Another critical factor is the strength of the materials used in the bearing's construction. Advanced materials, such as hybrid ceramics or specialized alloys, can significantly enhance the bearing's load-bearing capacity. These materials are engineered to resist deformation and wear under stress, providing superior durability compared to conventional materials. The ability of these materials to maintain their structural properties under extreme conditions of load, temperature, and vibration further extends the operating life of the bearing.

Load distribution is also a key determinant of dynamic load capacity. Bearings are designed to distribute loads evenly across their rolling elements and raceways. However, improper installation, misalignment, or uneven loading can result in localized stress concentrations, which may lead to premature fatigue failure. Ensuring that the bearing is properly aligned and that the load is distributed uniformly is essential for maximizing dynamic load capacity.

The design of the bearing itself is another critical aspect. Modern bearings are designed with advanced geometries and optimized internal structures to maximize load-carrying capacity while minimizing friction and wear. Innovations in bearing design, such as the use of larger rolling elements, enhanced contact angles, and optimized raceway profiles, contribute to improved dynamic load endurance. These design improvements not only

increase the load capacity but also enhance the overall efficiency and performance of the bearing.

Given the importance of dynamic load capacity, it is essential to prioritize the design, material selection, and maintenance of bearings in high-performance systems. Bearings with high dynamic load capacities can operate longer without failure, reducing the risk of expensive repairs, unplanned downtime, and equipment failure. In wind turbines, for example, where reliability is critical for continuous energy generation, ensuring high dynamic load capacity helps prevent costly shutdowns and maintenance. Similarly, in vehicle engines and industrial machinery, durable bearings contribute to smoother operation, reduced maintenance costs, and extended service life.

The dynamic load endurance capability of rolling contact bearings is a multifaceted attribute that influences the performance and longevity of mechanical systems across various industries. By focusing on high-quality materials, optimal design, proper lubrication, and even load distribution, engineers can enhance the dynamic load capacity of bearings, leading to improved reliability, reduced maintenance, and longer operational life. This study undertook the comprehensive formulation of both static and dynamic load enduring capacities for wind turbine generator bearings, incorporating constraint functions that ensure the bearings meet the performance and safety requirements in high-demand operational environments. Central to this approach were the equations and methodologies put forth by Duggirala et al. (2018), which provide a robust framework for modelling the behaviour of bearings under varying load conditions, particularly in the challenging context of wind turbine systems [8].

In wind turbine applications, bearings are subject to highly dynamic and fluctuating loads due to the ever-changing wind conditions and the mechanical demands of power generation. The static load enduring capacity of a bearing refers to its ability to withstand stationary or slowly varying loads without undergoing plastic deformation or structural failure. This parameter is essential for ensuring the bearing can maintain its integrity during infrequent, high-load events, such as gusts or mechanical braking situations, where excessive forces may be applied.

On the other hand, the dynamic load capacity of a bearing is concerned with its ability to endure continuous or cyclic loading over time without succumbing to fatigue. For wind turbines, this is critical because the rotating motion of the turbine blades and the gearbox places significant and repeated stresses on the bearings. These stresses, if not properly managed, can lead to fatigue-related failures such as pitting or spalling, which compromise both performance and longevity. Therefore, accurately formulating dynamic load capacity is key to ensuring that bearings can function reliably over the long-term operational life of the turbine.

The use of constraint functions in this study is pivotal for ensuring that the designed bearing meets all necessary operational, safety, and longevity criteria. Constraint functions help define the boundaries within which the bearing's design must operate, ensuring that it satisfies conditions such as maximum allowable deformation, material stress limits, and

thermal constraints. These functions also help ensure that the bearing can operate effectively under varying load and environmental conditions without exceeding design thresholds that could lead to premature failure.

The equations provided by Duggirala et al. (2018) serve as the foundation for these formulations. Their work presents detailed mathematical models that account for the complex interplay between material properties, load distribution, and bearing geometry. These equations offer a high level of precision in predicting how a bearing will perform under both static and dynamic loads, making them highly valuable for optimizing bearing designs in wind turbine applications. Additionally, Duggirala et al.'s approach includes considerations for factors such as friction, lubrication, and temperature effects, which further influence the bearing's load-carrying capacities and overall durability.

By integrating these established equations into the study, a more accurate and reliable assessment of the bearing's capabilities was achieved, allowing for the design of wind turbine generator bearings that can withstand the unique challenges posed by fluctuating wind speeds, varying load distributions, and harsh operational environments. This formulation ultimately contributes to the development of more robust wind turbine systems, which are crucial for enhancing the efficiency and sustainability of wind energy generation.

This study's formulation of static and dynamic load enduring capacities, along with the incorporation of constraint functions, provides a comprehensive method for designing high-performance wind turbine generator bearings. Utilizing the equations from Duggirala et al. (2018) ensures that these bearings can handle the rigorous demands of both stationary and dynamic loads, ultimately improving the reliability, longevity, and efficiency of wind turbine systems.

3. Optimization Algorithm

Population Setup: The process begins by generating an initial population, which consists of a diverse set of potential solutions, commonly referred to as chromosomes in the context of genetic algorithms. Each chromosome corresponds to a unique design configuration for the bearing, capturing key factors such as material properties (e.g., steel, hybrid ceramic materials) and geometric parameters (e.g., diameter, raceway curvature, and contact angles). This diversity in the population ensures that a wide variety of design alternatives are considered, allowing the algorithm to explore different pathways toward an optimized bearing design. By incorporating multiple variables into each chromosome, the initial population covers a broad spectrum of potential solutions, setting the stage for robust optimization.

Parameter Setting: After establishing the initial population, it is necessary to configure several key parameters that will guide the evolutionary process. The first step is to set the initial probabilities for crossover and mutation, two critical mechanisms in genetic algorithms. Crossover, which mimics the biological process of reproduction, combines information from two parent chromosomes to generate new offspring. Mutation introduces small random changes in a chromosome, encouraging exploration of novel design solutions.

The population size—the number of chromosomes in each generation—must also be determined, balancing computational efficiency with the need for sufficient diversity. Additionally, the number of generations, or iterations, that the algorithm will run must be defined. Another key aspect is the dynamic adjustment of crossover and mutation probabilities, which allows the algorithm to adapt as it progresses, potentially enhancing the search for optimal solutions.

Fitness Evaluation: Once the population is established and parameters are set, each chromosome undergoes a fitness evaluation, which quantifies how well the corresponding bearing design performs in terms of both static and dynamic load capacities. Static load capacity refers to the bearing's ability to withstand stationary or slowly changing loads without permanent deformation, while dynamic load capacity measures the bearing's resilience under cyclic or fluctuating loads over time. The fitness score is a composite measure, factoring in the importance of both static and dynamic capacities to ensure that the bearing design excels in both dimensions. A higher fitness score reflects a design that meets or exceeds performance expectations in these critical areas, ensuring both durability and reliability. The evaluation process ensures that each design's performance is rigorously assessed against key engineering criteria, promoting convergence toward optimal solutions.

Dynamic Probability Adjustment: As the algorithm progresses through generations, the diversity of the population may begin to decline, with many chromosomes becoming similar to one another. This phenomenon, known as convergence, can lead to premature optimization, where the search becomes trapped in a local minimum rather than exploring the broader design space. To counter this, the algorithm dynamically adjusts the probability of crossover based on population diversity. If the population exhibits low diversity, meaning the designs are converging too quickly and exploring fewer options, the crossover probability is increased. This encourages more mixing of genetic material between chromosomes, promoting the exploration of new design possibilities and enhancing the overall search for optimal configurations. The dynamic adjustment of crossover is a key feature that allows the algorithm to remain flexible and adaptive, avoiding stagnation in the search process. The calculation for adjusting the crossover probability follows Eq. (1), which is tailored to ensure an optimal balance between exploration and exploitation of the design space.

$$C_{dyn} = 0.4 + \{0.2(\frac{I}{I_{max}})^{\sqrt{3}}\} \quad (1)$$

C_{dyn} represents the dynamic crossover probability. I stands for the current count of iteration and I_{max} indicates the maximum count of iteration. Adjust the mutation probability depending on how quickly fitness scores are improving. If improvement slows down, increase the mutation rate to introduce new variations and prevent the algorithm from getting stuck in a suboptimal solution. The mutation probability has been calculated as per Eq. (2).

$$m_{dyn} = 0.02 + \{0.01(\frac{I}{I_{max}})^{\sqrt{3}}\} \quad (2)$$

m_{dyn} represents the dynamic mutation probability.

This approach, which combines population setup, careful parameter setting, fitness evaluation, and dynamic probability adjustment, is designed to systematically and intelligently optimize the bearing design. By ensuring diversity in the population and dynamically adapting the algorithm's key parameters, this methodology allows for the continuous refinement of bearing configurations, ultimately leading to an optimized solution that meets the demanding requirements of both static and dynamic load capacities in critical applications such as wind turbines or other high-performance machinery. This iterative process ensures that the final designs not only meet current performance standards but are also resilient and efficient over extended operational lifetimes.

Selection: In this phase, chromosomes (which represent potential design solutions) are chosen from the population based on their fitness scores. A fitness score is a quantitative measure of how well a design meets the desired objectives, such as maximizing load capacities or minimizing power loss in mechanical systems like hybrid bearings or wind turbine components. The selection process typically follows a strategy that favours individuals with higher fitness, meaning that the more optimized a design is, the higher the probability it will be chosen for reproduction. Various selection methods can be applied, such as roulette wheel selection, tournament selection, or rank-based selection. In these methods, fitter chromosomes, representing superior design configurations, are given a higher likelihood of passing their characteristics to the next generation. This strategy ensures that the evolutionary process is biased toward preserving and propagating the traits of high-performing designs while allowing for a diverse pool of solutions.

Crossover: Once parent chromosomes have been selected, the crossover process begins. Crossover, also known as recombination, is a key mechanism that allows for the mixing of genetic material between two parent chromosomes to create offspring. This phase is driven by the crossover probability, which dictates how frequently pairs of parents exchange their design traits. By combining and mixing different parts of the parents' design parameters, crossover can produce offspring with a blend of features from both parents, potentially leading to superior performance in the next generation. For example, in the context of optimizing wind turbine components, the crossover might result in a new design that inherits the high static load capacity of one parent and the low frictional power loss of another, combining the best of both worlds. The crossover process mimics biological reproduction, introducing new and potentially more efficient design configurations into the population. Different crossover techniques, such as single-point, two-point, or uniform crossover, can be applied based on the problem's complexity and the genetic algorithm's setup.

Mutation: While crossover introduces new combinations of existing traits, mutation brings entirely new genetic material into the population by randomly altering some of the design traits in the offspring. This phase is controlled by the mutation probability, which determines the likelihood that a given trait in the offspring will undergo a change. Mutation helps maintain diversity within the population by preventing premature convergence to suboptimal solutions and allowing the exploration of previously unexplored areas in the design space. This is particularly important in problems involving complex, multi-objective optimization, such as balancing static and dynamic capacities in mechanical systems. The

introduction of random mutations can lead to innovative and unexpected solutions that could outperform even the best designs from previous generations. By incorporating a degree of randomness, mutation ensures that the genetic algorithm doesn't stagnate and continues to explore a broad range of potential designs, increasing the likelihood of discovering the global optimum.

Evaluation of Offspring: After crossover and mutation have produced a new set of offspring, the next step is to evaluate their performance. This involves calculating the fitness scores of the offspring using the same criteria applied to the initial population. For each new design configuration, key performance metrics—such as load capacity, efficiency, and material strength—are assessed to determine how well the offspring designs align with the desired optimization goals. In the context of engineering problems, this evaluation might involve running complex simulations, mathematical models, or real-world experiments to measure the offspring's performance against specific design criteria. The evaluation process ensures that only the most promising designs are considered for inclusion in future generations.

Replacement: To create the new generation, the algorithm replaces the least fit members of the current population with the highest-performing offspring. This replacement strategy, sometimes referred to as "survivor selection," ensures that the population continues to evolve toward better design solutions. By removing poorly performing designs and introducing fitter offspring, the algorithm incrementally improves the overall quality of the population. This process mimics natural selection, where weaker designs are gradually eliminated from the pool, and stronger, more optimized designs dominate. In some algorithms, elitism may be employed, where the best-performing designs from the current generation are guaranteed to survive and carry over to the next generation. This helps preserve exceptional designs and prevents them from being lost due to stochastic events in the crossover or mutation phases.

Convergence Check: Throughout the evolutionary process, the algorithm monitors the population to check for signs of convergence. Convergence occurs when the fitness scores of the population reach a plateau, indicating that further iterations are unlikely to yield significant improvements. If the fitness scores stop improving for a set number of generations, or if the maximum number of generations is reached, the algorithm halts. This ensures that computational resources are not wasted on unnecessary iterations once the population has stabilized around an optimal or near-optimal solution. The convergence check is crucial for balancing exploration and exploitation, ensuring that the algorithm does not terminate prematurely while also avoiding excessive computation without meaningful gains.

Output: Once the algorithm converges or reaches its termination criteria, the final population is analysed to identify the best design(s). These optimal solutions represent the configurations that provide the highest static and dynamic load capacities, or whatever objectives were set for the optimization. Depending on the complexity of the problem, the output may consist of a single best design or a set of equally optimal solutions, each offering a different trade-off between objectives. These final designs serve as the ultimate goal of

the optimization process, representing the most efficient, cost-effective, and high-performing solutions discovered by the genetic algorithm. In practical applications, these designs can then be implemented in real-world systems or further refined through additional testing and validation.

Termination: The termination phase marks the conclusion of the genetic algorithm's execution. The output at this stage includes the optimal design parameters, along with a detailed assessment of their performance in terms of static and dynamic capacities. The best design(s) identified by the algorithm can then be used to guide engineering decisions, whether for improving mechanical components like bearings or optimizing large-scale systems such as wind turbines. The final solution provides insights not only into the optimal design but also into the underlying trade-offs that were considered during the optimization process, offering valuable knowledge for future design iterations.

4. Results and Discussion

The optimization of static and dynamic load capabilities in hybrid ceramic ball bearings, particularly within wind turbine generators, has undergone a transformative advancement through the application of a genetic algorithm enhanced with a dynamic function for assigning probabilities to the crossover and mutation processes. Unlike traditional fixed-probability approaches, this dynamic adjustment allows the algorithm to adapt to the evolving needs of the search process. In the early stages, the algorithm can prioritize exploration by increasing the probability of crossover, thereby encouraging a broader sampling of the design space and fostering innovation through diverse trait combinations. As the optimization progresses and the population of design solutions converges, the algorithm adjusts these probabilities, reducing excessive exploration and focusing more on fine-tuning and exploiting promising solutions. This dynamic shift in crossover and mutation probabilities helps prevent premature convergence to suboptimal designs while ensuring that the solution space is comprehensively explored.

This method has proven especially beneficial for the complex task of optimizing hybrid ceramic ball bearings, which are critical to the performance and longevity of wind turbine generators. These bearings must withstand varying loads and harsh operational conditions, making it essential to maximize both static and dynamic load capacities. The dynamic probability function allows the algorithm to identify superior bearing configurations that balance these competing demands, achieving a more robust and durable design. By effectively navigating the trade-offs between exploration (searching broadly for new solutions) and exploitation (refining known good solutions), the algorithm not only accelerates the convergence to optimal designs but also ensures that these solutions are resilient across a wide range of operating conditions.

Moreover, the design space in which this optimization occurs is governed by specific boundaries for each variable, as outlined in Table 1, which follows the industry-standard catalogue [9]. These constraints ensure that the optimized designs remain feasible and manufacturable within industrial tolerances, aligning theoretical advancements with practical applicability. The algorithm's ability to dynamically adjust crossover and mutation

probabilities while respecting these industrial constraints has resulted in significant improvements in the overall performance and reliability of hybrid ceramic ball bearings in wind turbine applications, positioning this approach as a cutting-edge solution in the field of renewable energy technologies.

Design Variable	Lower Limit	Upper Limit
Bearing Inner Diameter	120 mm	180 mm
Bearing Outer Diameter	260 mm	380 mm
Ball Diameter	10 mm	20 mm
Bearing Width	55 mm	75 mm
Rolling Element Count	20	45

Table 1. Design Variable Limits

Notable advancements in the optimization of hybrid ceramic ball bearings for wind turbine generators have resulted from the application of the genetic algorithm with dynamic functions for crossover and mutation probability. In particular, as compared to the conventional genetic algorithm that used fixed crossover and mutation probabilities of 0.6 and 0.03 respectively, this dynamic technique produced an increase in static load capacity of 11.25% and an increase in dynamic load capacity of 11.90%. Figures 1 and 2, respectively, visually represent the optimization outcomes achieved with the genetic algorithm using static and dynamic methodologies for allocating the crossover and mutation probabilities.

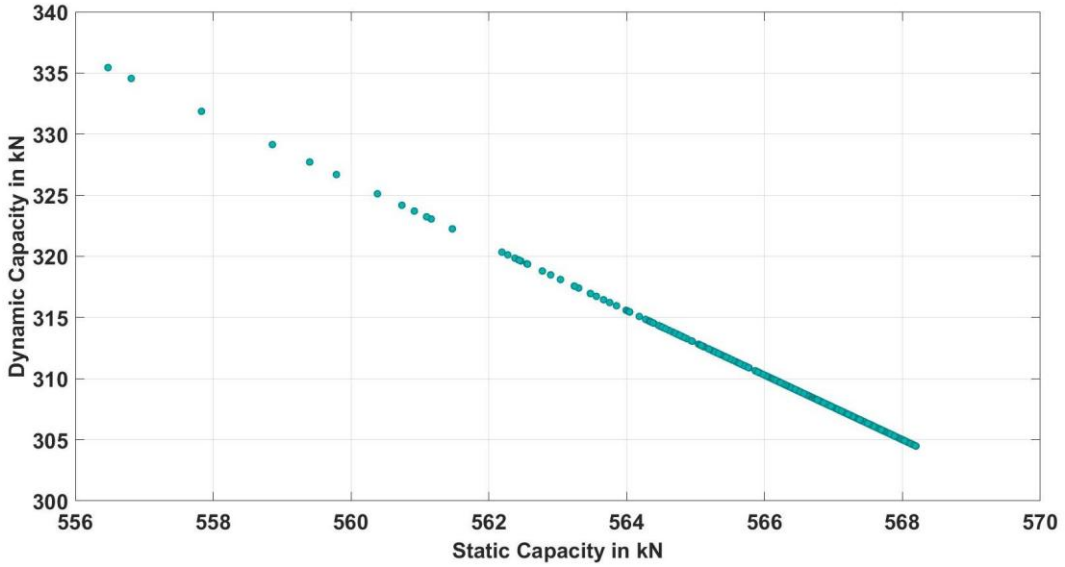

Fig. 1: Pareto Front Achieved by Using the Static Method to Determine the Crossover and Mutation Process Probabilities of Genetic Algorithm

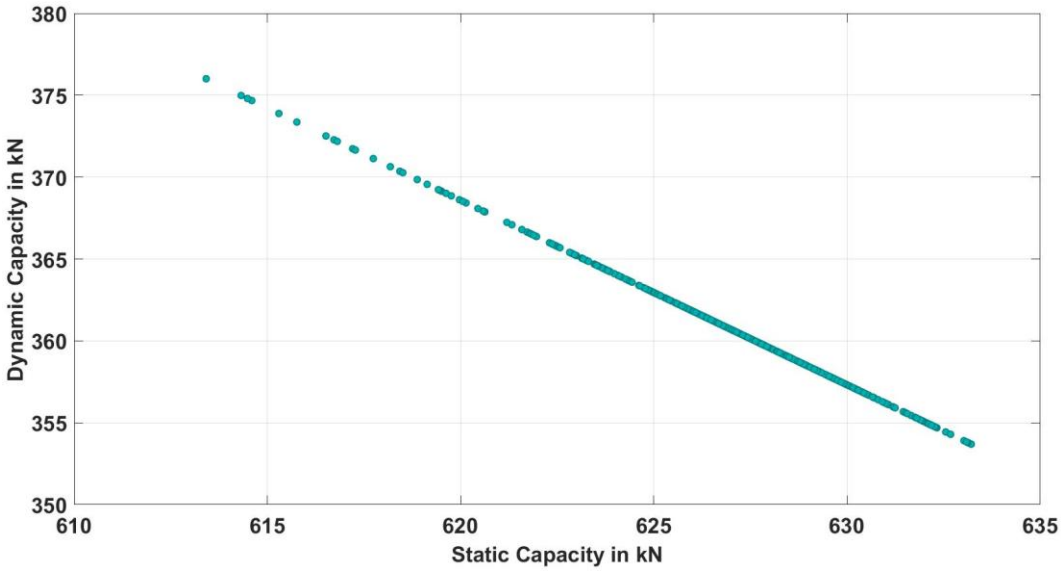

Fig. 2: Pareto Front Achieved by Using the Dynamic Method to Determine the Crossover and Mutation Process Probabilities of Genetic Algorithm

It is clear how useful it is to dynamically modify crossover and mutation probability when comparing the dynamic and static approaches to genetic algorithm implementation. Although more straightforward, the fixed technique is less flexible to adjust to the evolving requirements of the optimization process. On the other hand, the dynamic algorithm can adapt to the population's state at each iteration, changing the mutation probability when fitness gains stall out to prevent premature convergence and raising the crossover probability when population diversity is low to explore new regions of the design space. Because of its flexibility, the algorithm may break free from local optima and explore a wider range of possible design configurations, which improves performance overall. To achieve a more comprehensive exploration of the design space and improve the algorithm's capacity to converge on superior solutions, the ability to modify these probabilities throughout the optimization process proved crucial.

The results of this study have important ramifications for wind turbine generator design and optimization, especially with regard to enhancing bearings' static and dynamic load capabilities. By increasing uptime and lowering maintenance costs, these advancements can raise the overall efficiency and dependability of wind turbines, which is essential for the sustainability of the wind energy industry. Additionally, the paper makes the case that improved bearing longevity can increase trust in wind energy and hasten its widespread adoption. Future studies might look at multi-objective optimization, adaptive optimization utilizing real-time data, and the application of the dynamic genetic algorithm to additional wind turbine components. Furthermore, machine learning methods might improve the optimization procedure even further.

5. Conclusion

The optimization of static and dynamic load capacities in hybrid ceramic ball bearings for wind turbine generators, utilizing a genetic algorithm with dynamic probability assignment for crossover and mutation processes, has demonstrated substantial improvements in both performance and reliability. By leveraging the dynamic modification of these probabilities, the algorithm effectively balanced exploration of the design space with focused refinement, leading to the discovery of highly optimized bearing configurations. This adaptive strategy not only accelerated the convergence to optimal solutions but also enhanced the diversity of the solutions, preventing premature stagnation and ensuring thorough exploration of potential designs.

The proposed method addresses the critical need for durable, high-capacity bearings capable of withstanding the rigorous operational demands of wind turbine generators, where reliability is paramount. The genetic algorithm's ability to dynamically adjust its search strategy enabled it to discover novel configurations that maximize both static and dynamic load capabilities while remaining within the practical constraints provided by industrial standards. This approach has proven particularly effective in managing the complexity of hybrid ceramic ball bearing design, where multiple objectives and trade-offs must be considered simultaneously.

The integration of industry-standard limits, as defined in the SKF (2022) catalogue, further strengthens the practical relevance of the findings, ensuring that the optimized designs are manufacturable and viable for real-world applications. This research paves the way for further innovations in bearing design, offering valuable insights that can be applied to other mechanical components within renewable energy systems.

In summary, the dynamic genetic algorithm presented in this study marks a significant step forward in optimizing critical components of wind turbines, contributing to more efficient, reliable, and long-lasting renewable energy solutions. Future research can build upon this foundation by exploring additional design variables, incorporating new materials, or extending the methodology to other key elements in renewable energy systems.

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PRODUCTIVITY IN A WATERFALL VERSUS AGILE DEVELOPMENT TEAM

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Abstract

This research delves into a comparative analysis of productivity in Waterfall and Agile development teams. It challenges the traditional metrics of productivity, like lines of code and hours worked, revealing their limitations in the complex realm of software development. The study emphasizes the need to consider both qualitative aspects - such as code quality and team collaboration - and quantitative measures. It explores how Waterfall and Agile methodologies influence team dynamics, efficiency, and project success, providing insights through industry examples and modern tools. The comparison presents a comprehensive view of evolving productivity metrics in software development.

This article comprehensively explores the various reasons why Agile methodology is widely considered to significantly enhance productivity compared to the Waterfall approach.

Though both methodologies contribute to increased productivity, Agile distinguishes itself through its inherent characteristics that prove advantageous not only for achieving project success but also for the well-being of developers..

Keywords: Productivity, software development, Waterfall, Agile, Code quality, Project impact, Quantitative and qualitative measurements, dynamics

JEL Classification: C61

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1. Introduction

1.1. Overview of Waterfall and Agile Methodologies

The Waterfall methodology, conceived in the 1970s, is based on a sequential structure, where each phase of a project must be completed before moving on to the next one. The Waterfall is effective for projects with well-defined and stable requirements, where the end goal is clear and no significant changes are expected along the way.

Agile, a term that took hold in the software industry in the early 2000s, is founded on the Agile Manifesto, a set of principles designed to improve software development. This methodology evolved in response to the rigidity and limitations of traditional development processes. Agile emphasizes adaptability, cross-disciplinary collaboration, and continuous feedback, allowing teams to respond quickly to change. By breaking down projects into small, manageable segments (sprints), Agile facilitates continuous and flexible software delivery, focused on customer needs.

The main difference between Agile and Waterfall is flexibility. Agile allows for quick adaptation to changes, while Waterfall follows a strict and well-defined plan. Despite the differences, both approaches aim to deliver high-quality software and meet project goals. Waterfall is preferred for projects with clear and unchanging requirements, while Agile is ideal for projects where requirements evolve.

Agile and Waterfall have had a significant impact on the way software is developed and delivered. Agile has ushered in a new era of flexibility, collaboration, and adaptability, while Waterfall continues to be relevant for projects with well-defined parameters. The choice between these methodologies depends on the nature of the project, the culture of the organization, and the needs of the customers [1].

1.2. Overview of Productivity Measurements

In the world of software development, productivity measurement is a complex area that is essential for optimizing processes and ensuring efficient product delivery. Traditional metrics, such as the number of lines of code written or bugs fixed, are no longer sufficient to capture the essence of true productivity in such a dynamic and innovative environment.

Lines of code are not necessarily correlated with a better product. On the contrary, more lines of code can show a bad organization of the overall project, either due to the existence of duplicate code or to unnecessary complications of a task [2]. This can lead to a higher level of complexity and an increased chance of errors and future issues.

Furthermore, the number of bugs fixed is not a reliable indicator of efficiency, given the fact that a large number can result from poorly written code. Therefore, greater emphasis

should be placed on minimizing the time taken to fix bugs or to have as few bugs as possible.

Measuring the amount of code produced or bugs fixed and focusing on quantity over quality isn't an effective way to understand productivity. In contrast, modern approaches focus on a more diverse set of metrics that are more relevant to today's reality.

Measuring developer productivity typically boils down to tracking the work completed and the quality or importance of the task accomplished. By combining these two criteria, the monitoring of productivity ensures project success.

One notable example is Cycle Time, which tracks a task's duration from start to completion. It provides valuable insight into the efficiency of development processes. For example, in an Agile team, a short cycle time can indicate rapid responsiveness to requirements and excellent adaptability. On the other hand, Deployment Frequency measures how often the team releases software or updates. In a Waterfall environment, where deployments are less frequent but more comprehensive, this metric may reflect a more meticulous and structured development process.

The rework rate, which indicates the percentage of tasks requiring revision or correction after completion, is another critical indicator. A high rate may suggest problems in requirements definition or internal communication. In addition to these quantitative measures, qualitative assessment of productivity, such as feedback from colleagues and the quality of collaboration, plays a key role.

In recent years, innovative metrics have emerged that have enriched the productivity measurement landscape. DevOps Research and Assessment (DORA) metrics, such as change response time and system stability, are used extensively in the DevOps industry to evaluate and improve development and operational processes [3]. Covering a wide range of issues, another set of metrics addresses aspects such as employee satisfaction, well-being, performance, activity, communication, collaboration, efficiency, and workflow. These metrics are collectively known as SPACE.

A concrete industry example is Google's approach, which combines log analysis with socio-technical assessments to understand developer productivity better [4]. This blended methodology not only assesses what developers do but also how they feel about their work, a key aspect of maintaining sustainable productivity. Companies like Microsoft are integrating DORA metrics into their DevOps processes, aiming for continuous improvements in team performance. Tech startups also often adopt SPACE metrics to assess employee satisfaction and team effectiveness, reflecting a shift in how the industry values and measures productivity.

The multidimensional approach to these metrics reflects the continuing evolution of the industry and the need to assess productivity in a more holistic way adapted to contemporary realities.

2. Theoretical Background

The theoretical underpinnings of modern software development methodologies and metrics represent a paradigm shift in how productivity and efficiency are understood and measured in the software industry. This shift reflects an acknowledgment of the multifaceted nature of software development, extending beyond technical output to include human factors and the quality of the work environment. These contemporary approaches, grounded in diverse disciplines, highlight the necessity of adaptable, iterative methodologies and holistic metrics. They emphasize the significance of balancing technical efficiency with the well-being of development teams and the satisfaction of end-users, crucial for sustainable and successful software development in today's dynamic technological landscape.

2.1. Agile Development Evolution

The Agile development approach [5] moves from rigidity to flexibility. The evolution from traditional to modern methodologies in software development signifies a shift from structured, plan-driven processes to more adaptable, iterative approaches. This transition has been driven by the increasing complexity of software projects, necessitating methods that can accommodate rapid changes and deliver solutions more efficiently.

Incorporating feedback loops and team collaboration means that modern methodologies, especially Agile, emphasize the importance of regular feedback loops and team collaboration. This perspective is rooted in the idea that continuous improvement and adaptation, coupled with empowered, self-organizing teams, lead to higher productivity and innovative solutions.

2.2. Modern Metrics

Modern metrics to be considered include:

- DORA Metrics in the DevOps Context: Emerging from the need to enhance software development and operations, DORA metrics embody principles of continuous integration and deployment. These metrics, which include deployment frequency and mean time to recover, underscore the importance of swift and resilient software delivery in DevOps.
- Cycle Time and Efficiency: Drawing from lean manufacturing, Cycle Time in software development measures the efficiency of the development process from start to finish. It reflects a focus on minimizing waste and optimizing process efficiency, crucial in the Agile framework for rapid and responsive software delivery.

- SPACE Framework: A Holistic Approach: SPACE, encompassing Satisfaction, Performance, Activity, Communication, and Efficiency, offers a comprehensive view of productivity. This framework challenges the notion that productivity is solely quantifiable, integrating qualitative aspects such as team satisfaction and communication effectiveness.
- Qualitative Measurements: A Human-Centric View: Recognizing software development as a human-centric process, modern metrics also focus on team dynamics, creativity, and user satisfaction. These qualitative measures assess aspects often overlooked by traditional metrics, emphasizing the importance of team morale and customer satisfaction.

3. Factors Influencing Productivity

A study performed by Babu Veeresh Thummadi and Kalle Lyytinen [6] shows that methodologies like Waterfall and Agile have an impact of 40% on a project. This means that development strategies play a significant role in shaping the trajectory of the overall process. However, it's crucial to recognize that the remaining 60% of the equation is intertwined with the intricate tapestry of individual contributions, project-specific conditions, and the unpredictable nuances of the project's environment. This means that the people involved, the unique circumstances of the project, and the external influences on the development landscape contribute to the overall productivity and success of a software project.

By analogy, it can be stated that developers' productivity level is closely linked to factors such as motivation, customer satisfaction, mental health, and team dynamics.

3.1. Motivation in Workspace

Motivation plays a role in driving developers to consistently produce high-quality work.

Intrinsic motivation, which stems from personal interest or enjoyment in the task itself, is a key driver in workplace productivity. Ryan and Deci's Self-Determination Theory (SDT) [7] highlights the importance of intrinsic motivation in fostering employee engagement and satisfaction. In the context of software development, methodologies that offer autonomy, mastery, and purpose, like Agile, tend to enhance intrinsic motivation among developers.

Locke and Latham's Goal Setting Theory [8] suggests that clear, challenging goals and appropriate feedback contribute to higher levels of employee motivation. Agile methodology, with its iterative cycles and continuous feedback, aligns well with this theory. In the Agile methodology, which promotes collaborative development, motivation thrives thanks to its focus on quick feedback and adaptability. On the other hand, the Waterfall

model follows a progression where sustained motivation might be challenged due to longer feedback cycles and difficulty incorporating changes.

The impact of recognition and rewards on motivation is well-documented. Herzberg's Two-Factor Theory [9] considers that while certain factors (like salary and job security) prevent dissatisfaction, it's factors like recognition and achievement that truly motivate employees. Agile methodologies often incorporate regular reviews and acknowledgments of achievements, which can positively impact motivation. This regular recognition provides immediate gratification and acknowledgment of developers' efforts, contributing to a more motivated workforce.

Transformational leadership, which involves inspiring and motivating team members towards a collective goal, is particularly effective in Agile environments. Leaders who demonstrate vision, provide inspiration, and encourage intellectual stimulation can significantly enhance the motivation and productivity of their teams [10].

Both approaches prioritize customer satisfaction, but the iterative nature of the Agile model allows for frequent customer involvement and adjustments, resulting in a more satisfying outcome for the customer and higher levels of satisfaction for developers [11].

The study performed by A. Westendorp reveals that Agile teams exhibited a more robust knowledge network in contrast to their Waterfall counterparts. Additionally, there was an adverse relationship between knowledge boundaries and the transactive memory system within waterfall teams. Furthermore, the transactive memory system demonstrated a positive correlation with both team satisfaction and perceived team productivity, further highlighting potential limitations within the waterfall methodology [12].

3.2. Mental Health

The environment in which software developers work can significantly influence their mental health. Studies have shown that high-stress environments, characterized by tight deadlines and heavy workloads, can lead to increased anxiety and burnout among developers. The Agile methodology, with its emphasis on regular breaks and a sustainable work pace (as outlined in the Agile Manifesto), can mitigate these stressors, promoting a healthier work environment [13].

Social support within the workplace plays a crucial role in the mental health of employees. Agile methodologies often foster a strong sense of community and collaboration, which can provide emotional and professional support to developers. This support system can be particularly beneficial in managing work-related stress and preventing feelings of isolation, common in more rigid and compartmentalized working environments like those found in Waterfall methodologies [14].

Mental health is crucial in software development, and Agile's emphasis on well-being can lead to a more pleasant and healthier work environment, considering the more rigid structure of Waterfall development.

3.3. Team Dynamics

Team dynamics are important for work quality in both methodologies. However, the fact that Agile emphasizes teams managing themselves encourages the formation of cross-functional teams and continuous collaboration promotes communication and an overall better synergy among team members, positively influencing productivity [15].

4. Advanced Metrics

4.1. Cycle Time

Ever since the 90s, a study of NPD best practices sponsored by the Product Development and Management Association [16] showed that nearly 41% of those surveyed indicated that their organizations were developing new products much faster than they did in the past 5 years. This is due to competition, but mostly to a shorter product life cycle and, implicitly, the growing need for new products. Even in the present time, the goal is to minimize cycle time so that new products are launched more quickly.

Cycle time can be influenced by a lot of factors, such as project complexity. Projects that involve advanced features, difficult algorithms, or integrations are often more challenging, so the development process tends to last longer.

Additionally, incorporating new technologies into software development can represent an advantage, as they are faster and support more functionalities needed by developers. However, the time required to learn how to use them can vary and become quite expensive, perhaps even to the point where using older technologies would have obtained the same results in a much shorter time. Therefore, team members must be carefully selected, ensuring they possess a high level of adaptability and quick learning skills.

Team members play an important part in the duration of task completion. For example, cross-functional teams including members with diverse skill sets can enhance productivity, reduce cycle time, and even create an environment conducive to innovation [17].

Product management is also a crucial element in reducing production time. That is why the well-defined and structured development processes successfully meet the expected deadlines. Consequently, cycle time can be directly related to project management methodologies, and reducing it is more likely to be achieved using Agile rather than Waterfall. Agile breaks down the project into manageable and small iterations, delivering a

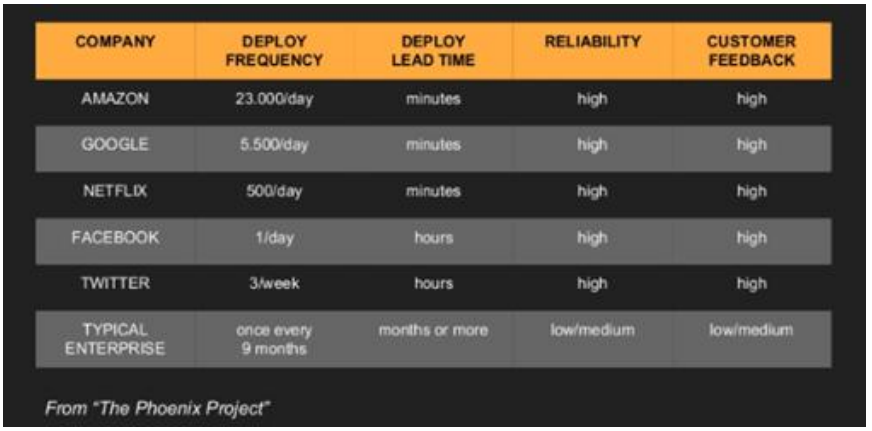
prototype at the end of every sprint. Hence, usable versions of the product are released faster, reducing the overall cycle time [18].

In addition, Agile methodology implies flexibility to change, so adapting to the customer needs and feedback doesn't cost as much time as if it were for a Waterfall project.

4.2. DORA Metrics

The DevOps Research and Assessment (DORA) metrics are a set of key performance indicators designed to measure the effectiveness of software development and delivery processes. Introduced by Dr. Nicole Forsgren, Jez Humble, and Gene Kim in the State of DevOps Reports, these metrics include four main areas: Deployment Frequency, Lead Time for Changes, Change Failure Rate, and Mean Time to Recovery (MTTR) [3].

Major tech companies like Google, Amazon, and Netflix have adopted DORA metrics to optimize their DevOps practices. For instance, Amazon reportedly deploys new software to production every 11.7 seconds [19], demonstrating a high Deployment Frequency. Netflix, known for its robust DevOps culture, emphasizes rapid recovery, aligning with the MTTR metric, to ensure the high availability and reliability of its streaming service.



COMPANY	DEPLOY FREQUENCY	DEPLOY LEAD TIME	RELIABILITY	CUSTOMER FEEDBACK
AMAZON	23.000/day	minutes	high	high
GOOGLE	5.500/day	minutes	high	high
NETFLIX	500/day	minutes	high	high
FACEBOOK	1/day	hours	high	high
TWITTER	3/week	hours	high	high
TYPICAL ENTERPRISE	once every 9 months	months or more	low/medium	low/medium

From "The Phoenix Project"

Figure 1. Comparison of Deployment Metrics Across Leading Tech Companies and a Typical Enterprise [20]

The table compares several major tech companies and a typical enterprise based on their deployment metrics. These metrics include Deployment Frequency, Deploy Lead Time, Reliability, and Customer Feedback. Amazon leads with 23,000 deployments per day and has a deploy lead time in minutes, along with high reliability and customer feedback. Google follows with 5,500 daily deployments. Netflix has 500 deployments per day, and

Facebook has one per day, both with high reliability and customer feedback. Twitter deploys three times a week, again with high marks in the remaining metrics. In contrast, a typical enterprise deploys once every 9 months, with longer lead times, and lower reliability and customer feedback. These metrics illustrate the efficiency and effectiveness of DevOps practices in these organizations.

In practice, these metrics are collected and analyzed through a combination of automated tools and processes. Deployment Frequency and Lead Time for Changes are often tracked using version control and continuous integration tools, while Change Failure Rate and MTTR are monitored through incident management systems. For instance, tools like Jenkins for continuous integration can provide data on deployment frequency, while JIRA or PagerDuty might be used to track incident response times and change failure rates.

The application of DORA metrics has led to significant improvements in software development and operational performance. Companies that excel in these metrics are often categorized as 'elite performers' in DevOps, showcasing higher deployment frequencies, faster lead times, lower change failure rates, and quicker recovery from incidents. This translates into faster time-to-market, improved customer satisfaction, and enhanced competitiveness in the industry.

Software delivery performance metric	Elite	High	Medium	Low
Deployment frequency For the primary application or service you work on, how often does your organization deploy code to production or release it to end users?	On-demand (multiple deploys per day)	Between once per week and once per month	Between once per month and once every 6 months	Fewer than once per six months
Lead time for changes For the primary application or service you work on, what is your lead time for changes (i.e., how long does it take to go from code committed to code successfully running in production)?	Less than one hour	Between one day and one week	Between one month and six months	More than six months
Time to restore service For the primary application or service you work on, how long does it generally take to restore service when a service incident or a defect that impacts users occurs (e.g., unplanned outage or service impairment)?	Less than one hour	Less than one day	Between one day and one week	More than six months
Change failure rate For the primary application or service you work on, what percentage of changes to production or released to users result in degraded service (e.g., lead to service impairment or service outage) and subsequently require remediation (e.g., require a hotfix, rollback, fix forward, patch)?	0%-15%	16%-30%	16%-30%	16%-30%

Figure 2. DORA Metrics Categorization for Software Delivery Performance [21]

The table outlines the categories of performance metrics for DevOps practices, classifying them into 'Elite', 'High', 'Medium', and 'Low' based on Deployment Frequency, Lead Time for Changes, Time to Restore Service, and Change Failure Rate.

While DORA metrics provide valuable insights, their implementation can be challenging, especially in organizations with legacy systems and traditional development practices. It requires a cultural shift towards embracing DevOps principles, investing in the right tools and technologies, and training teams to effectively leverage these metrics for continuous improvement.

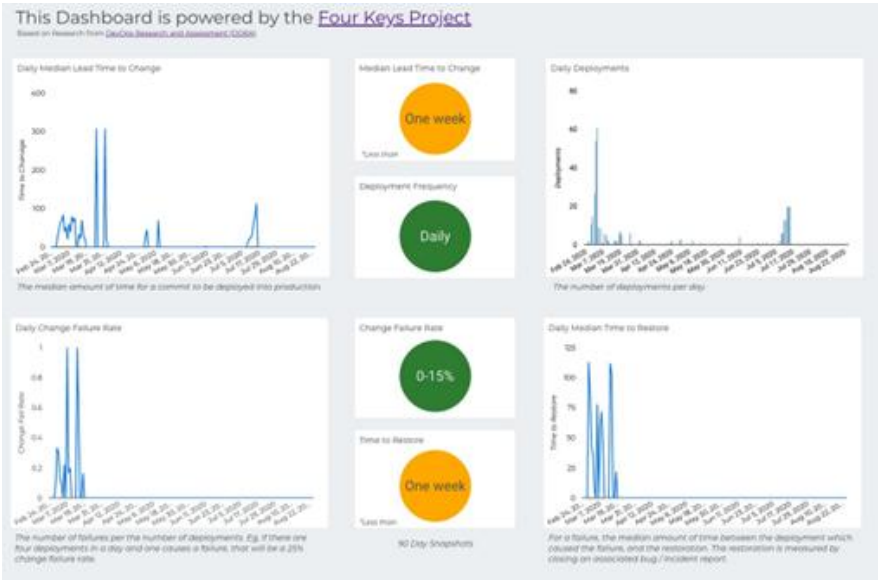


Figure 3. DevOps Performance Metrics Dashboard Based on DORA Research [21]

This dashboard presents a visual representation of key DevOps performance metrics over time, based on the Four Keys Project and DORA research. Daily Median Lead Time to Change: This chart shows spikes in the time it takes for changes to go from commit to production, suggesting variability in the process. The median lead time seems to fluctuate significantly over the months displayed. Daily Deployments: This histogram indicates the number of deployments per day, with noticeable peaks and troughs, implying inconsistency in the daily deployment frequency. Daily Change Failure Rate: The chart illustrates the ratio of deployments that fail, represented as a proportion. The data points show that most of the time, the change failure rate is low, with occasional spikes. Daily Median Time to Restore: This graph shows the time taken to restore service after a failure, with the median time also varying but with some high peaks, indicating instances of longer restoration times. In the center of the dashboard, summary metrics are provided: Median Lead Time to Change is summarized as "less than one week.", Deployment Frequency is noted as "daily.", Change Failure Rate is between "0-15%." and Time to Restore is summarized as "less than one week." This summarizes the overall performance, suggesting a generally high operational

standard, with daily deployments and change lead times and restoration times within a week, alongside a low change failure rate.

4.3. SPACE Metrics

Tech giants like Microsoft and Google have started to adopt frameworks like SPACE [22] to evaluate developer productivity. These companies recognize that productivity is not just about output but also about employee satisfaction, effective communication, and efficient workflows. For example, Microsoft uses various internal tools to gauge developer satisfaction and performance, integrating these insights into their software development process.

Implementing SPACE involves collecting data across different dimensions. Satisfaction can be measured through regular surveys and feedback mechanisms. Performance might be tracked via project milestones and individual contributions. Activity data can be gathered from version control systems. Communication effectiveness is often assessed through team meetings and collaborative tools analytics. Lastly, efficiency is evaluated by analyzing the time and resources utilized for completing tasks [23].

Adopting SPACE in an organization is not without challenges. It requires a cultural shift towards valuing qualitative aspects of work, as well as implementing systems for regularly collecting and analyzing diverse data types. Additionally, there is a need to balance the collection of these metrics with concerns about privacy and the potential for micromanagement. Ensuring that data collection is transparent and used constructively is crucial for the successful implementation of the SPACE framework.

When implemented effectively, SPACE can provide a comprehensive view of productivity, encompassing both the well-being of software developers and the efficiency of the development process. This holistic approach can lead to improved team morale, higher quality of work, and ultimately, more successful software projects. Companies that have embraced similar multifaceted productivity frameworks report better employee retention, increased innovation, and enhanced project outcomes [24].

5. Survey and Data Analysis

5.1. Survey Methodology

The survey methodology is based on the following principles:

- Data Collection Approach: A survey was conducted on a sample of 51 working students from the Polytechnic University of Bucharest, all within the age bracket of 21 to 23 years and with less than two years of experience in the IT industry. This demographic was selected to yield insights into the productivity and work habits of

nascent professionals in the IT field. The survey was disseminated using the public communication channels frequented by fourth-year students from the Faculty of Automatic Control and Computers.

- Survey Design: The survey was crafted to consist of three segments: participant sorting questions, main questions, and questions for understanding demographics.

The main questions concerned:

- Self-assessment of workplace productivity
- Perceived efficiency of the development model in use
- Average weekly time spent in team or managerial meetings
- Focus on discussions during meetings.
- The proportion of tasks completed within the initial time frame allocated
- Ease of finding help for tasks within their team.

The survey's design aimed to encapsulate a comprehensive understanding of the participants' experiences, measuring not only quantitative aspects such as task completion rates and meeting times but also qualitative dimensions like satisfaction with the development model and teamwork dynamics.

5.2. Survey Results and Interpretation

Data highlighted that a mere 3.8% of respondents were using the Waterfall methodology, while a significant majority of 84.6% employed Agile methodologies. This distribution underscores the prevalence and popularity of Agile practices among the participating companies and teams.

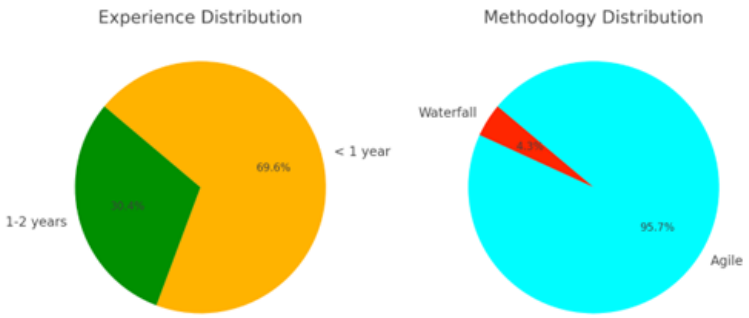


Figure 4. Analysis of Methodology Preference and Experience among Young Software Developers

The analysis highlights:

- Experience Distribution: The pie chart illustrates the distribution of experience among the students. 30.4% have 1-2 years of experience, while 69.6% have less than a year of experience in software development.
- Methodology Distribution: This pie chart displays the methodologies used by the students. Only 3.8% use the Waterfall methodology, whereas a significant majority of 84.6% use the Agile methodology.

The collected data revealed that Agile users reported an average productivity level of 7.5 out of 10 and rated the methodology's effectiveness at 7.8. Conversely, Waterfall users reported lower productivity and satisfaction levels, with scores of 6 (productivity level) and 5 (methodology rating). These findings illustrate a distinct preference for Agile in terms of both perceived productivity and satisfaction.

Regarding task completion, Agile practitioners reported an 83.2% success rate in completing tasks within the allocated time, slightly higher than the 80% reported by Waterfall users. Meeting durations varied, with Agile meetings averaging 3 hours weekly, typically in the form of daily stand-ups, compared to 2 hours for the more traditional, weekly Waterfall status meetings.

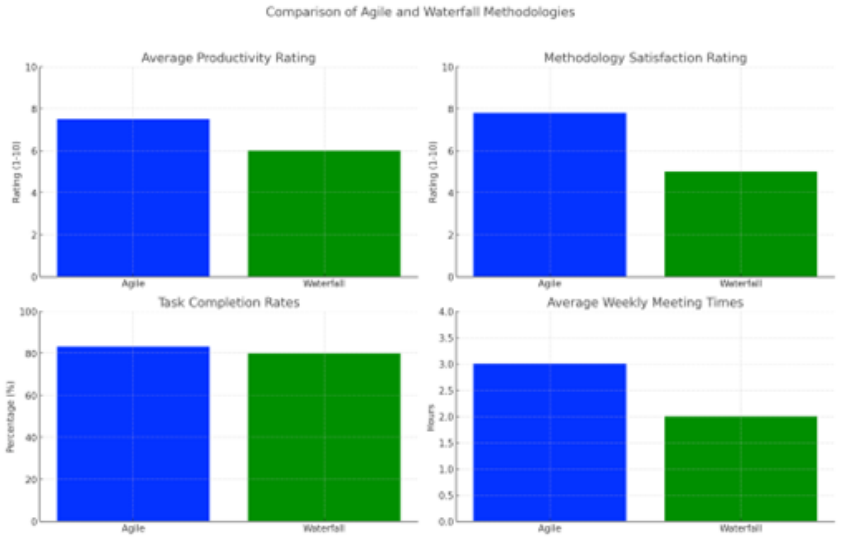


Figure 5. Comparative Analysis of Agile and Waterfall Methodologies Based on a Survey of Early-Career IT Professionals

The graphs present a comparison of Agile and Waterfall methodologies based on a survey conducted with early-career IT professionals. Average Productivity Rating: Agile

methodology users report higher productivity ratings, with an average score of around 7.5 out of 10, while Waterfall users report an average of 6. Methodology Satisfaction Rating: Satisfaction with the Agile methodology is higher, scoring around 7.8 out of 10, as opposed to a 5 for Waterfall. Task Completion Rates: Agile users report a higher task completion rate at approximately 83.2%, compared to 80% for Waterfall users. Average Weekly Meeting Times: Agile methodology entails longer weekly meetings, averaging about 3 hours, whereas Waterfall averages about 2 hours per week. These findings suggest that the Agile methodology is perceived to be more productive and satisfactory among the participants, with a slightly higher task completion rate and longer meeting times compared to the Waterfall methodology. The study highlights the prevailing preference for Agile practices among the surveyed early-career professionals.

As statistical relevance, it is imperative to note the limited representation of Waterfall methodology among the survey participants. This underrepresentation may skew the comprehensiveness of the data related to Waterfall, necessitating a cautious interpretation of these results.

The overarching aim of this survey was to acquire empirical evidence on the efficacy and perceived productivity of Agile versus Waterfall methodologies among budding IT professionals. The study meticulously evaluated factors such as self-assessed productivity, developmental model efficiency, meeting durations, the focus of discussions, task completion rates, and the ease of obtaining assistance within teams. The subsequent analysis endeavors to provide an exhaustive overview of how these methodologies tangibly influence the daily working experiences of those just commencing their careers in the IT sector.

6. Conclusions

In conclusion, this article has delved into the multifaceted reasons why Agile methodology is a substantial enhancer of productivity compared to the traditional Waterfall approach. The core principles of collaboration, flexibility, and customer-centricity that underpin Agile, not only foster a more responsive and efficient work environment but also contribute to the superior productivity achieved through Agile methodology.

However, thoughtful consideration when selecting a development methodology is crucial. Project managers and teams should weigh the benefits and constraints of each approach against the unique characteristics of the project at hand. Software development has a dynamic nature, where there is a synergy between the chosen methodology and the collective efforts of the individuals involved. The adaptability to project conditions and environmental dynamics contributes significantly to the ultimate success and productivity of the endeavor.

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BUDGETING PROCESS IN SMALL AND MEDIUM-SIZED ENTERPRISES - STATISTICAL ANALYSIS OF SMES IN ALBANIA

Almina Doko[1]

Abstract

This paper examines the budgeting practices of small and medium-sized enterprises (SMEs) in Albania, emphasizing the critical link between effective budgeting and financial performance. The study begins by outlining the research context, objectives, and aims, followed by a comprehensive literature review of key budgeting theories and challenges faced by SMEs in implementing effective strategies. It assesses the impact of budgeting on financial performance and compares these practices with those in other Balkan countries. Utilizing a robust methodological framework, the research applies quantitative techniques, including linear regression and correlation analysis, to data from Albanian SMEs. The findings show significant correlations between structured budgeting and enhanced financial outcomes, highlighting the importance of sound financial management in improving SME performance. This study contributes to the literature by offering insights into Albanian SME budgeting practices and recommendations for strengthening them, highlighting budgeting's vital role in ensuring the financial sustainability and growth of SMEs in Albania.

Keywords: budgeting, financial performance, small and medium-sized enterprises, effective budgeting.

JEL Classification: G31, M29

1. Introduction

The budgeting process is one of the essential elements of financial management for any type of enterprise, but it is particularly important for small and medium-sized enterprises (SMEs). In Albania, SMEs are a significant part of the national economy and play an important role in job creation, innovation and economic development (INSTAT, 2021) [7]. However, these enterprises face significant challenges in managing their finances, especially in relation to the budgeting process. An effective budget is critical for allocating resources, planning investments and maintaining a stable level of liquidity, but SMEs often struggle to implement well-structured budgeting processes due to a lack of expertise and

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limited financial resources (OECD, 2019) [14]. Budgeting is the process that involves determining the income and expenses of an enterprise for a given period of time and is a key component for the financial security of enterprises. For SMEs, budgeting involves not only forecasting income and expenses, but also managing cash flow, controlling costs, and making strategic investment decisions (Bruns & Waterhouse, 2020) [1]. A well-structured budget helps enterprises cope with market uncertainties and adapt to changes in demand and supply. SMEs in Albania face difficulties such as limited access to financing, lack of technological capacity, and lack of advanced financial knowledge, which affect the effectiveness of the budgeting process (European Investment Bank, 2022) [3].

In the framework of this study, the budgeting process in Albanian SMEs will be analyzed with the aim of identifying existing practices, key challenges and strategies that can improve this process. If the budgeting process is not well structured, SMEs may face a high risk of financial destabilization and even bankruptcy. The study aims to make an important contribution to the existing literature on the financial management of SMEs, focusing on the specific context of Albania, where the market structure and economic challenges are unique.

2. Literature review

Many previous studies have shown the importance of an effective budgeting process in SMEs. Bruns and Waterhouse (2020) [1] point out that enterprises that use clear and well-defined budgets tend to have a more stable financial performance and achieve higher long-term results. In a study conducted by the OECD (2019) [14], it was found that 70% of SMEs facing financial difficulties did not have structured processes for budget planning, underlining the importance of this aspect of financial management. In addition, a World Bank (2020) [19] report on financial management in Western Balkan countries identifies budgeting as one of the main challenges for the development and sustainability of SMEs. In Albania, the budgeting process for SMEs is also affected by factors such as lack of access to long-term financing and limited support from financial institutions (European Investment Bank, 2022) [3]. Due to these limitations, many SMEs conduct the budgeting process informally or intuitively, thereby increasing the risk of inaccurate financial forecasts and poor cost management. To address these challenges, SMEs need to develop a deeper understanding of modern budgeting methods and take advantage of new financial technologies, which can help automate and improve this process.

Another important aspect of budgeting in SMEs is the impact it has on the financial performance of enterprises. Various studies have shown that a well-structured budgeting process has a strong link to improved financial performance, especially in relation to increasing profits and optimizing costs (Lukka & Modell, 2021) [10]. Budgeting also helps in setting clear objectives and measuring performance, allowing SMEs to track progress and make necessary changes to their strategies to achieve long-term success.

Furthermore, an element that must be taken into account is the role of external factors in the budgeting process for SMEs. Changes in legislation, fiscal policies and the economic climate can significantly affect the way these enterprises develop and implement their budgets (Bruns & Waterhouse, 2020) [1]. For this reason, it is important for enterprises to

have flexibility in their budgeting process to adapt to possible changes and minimize the risks associated with them.

3. Research purpose

The purpose of this study is to analyze and evaluate the budgeting process in small and medium-sized enterprises (SMEs) in Albania, identifying the main challenges that these enterprises face in this regard and the impact that a well-structured budgeting process can have on their financial performance. This study also aims to propose practical strategies for improving budgeting in these companies, based on best practices and existing studies in this field.

3.1 Research Hypotheses

• Hypothesis 0: The budgeting process does not have a significant impact on the financial performance of small and medium-sized enterprises (SMEs) in Albania.

• Hypothesis 1: The budgeting process has a significant positive impact on the financial performance of small and medium-sized enterprises (SMEs) in Albania.

3.2 Methodology

This study will use quantitative methodology:

• Quantitative data: A survey will be conducted with owners and financial managers of small and medium-sized enterprises in Albania. This survey will be used to collect data on existing budgeting processes, challenges encountered and to measure the impact of budgeting on the financial performance of SMEs.

• Data analysis: The data will be analyzed using statistical analysis techniques for the quantitative part and content analysis for the qualitative part. Regression methods will be used to assess the relationship between budgeting and the financial performance of SMEs.

• Sample: The sample will include a selected group of SMEs operating in different sectors of the Albanian economy, with the aim of representing a broad picture of the challenges and opportunities of the sector.

4. Budgeting process in SME's and their challenges

Budgeting is an important process for effective financial management in small and medium-sized enterprises (SME's). It involves a series of steps that help organizations plan, monitor, and control their financial resources. However, SMEs face unique challenges in the budgeting process that help shape their financial management practices and strategies.

Steps of the Budgeting Process

The budgeting process involves several steps, which typically include:

Budget Preparation	Financial Forecasting	Budget Review and Approval	Monitoring and Control
This includes identifying the organization's strategic goals and objectives, as well as determining the financial resources necessary to achieve these objectives (Gjikondi, 2010) [5].	This step involves estimating potential revenues and expenses for future periods. In this phase, SMEs use historical data and economic indicators to forecast financial performance (Mino, 2014) [11].	After the budget is prepared, it must be reviewed and approved by management and, in some cases, by the board of directors. This is an important step to ensure that the budget is aligned with the overall strategy of the organization (Kopliku, 2017) [9].	After approval, it is important to monitor the budget execution. This step involves comparing actual expenditures and revenues with those forecasted and identifying any deviations that occur (Hoxha, 2018) [6].

Table 1: Steps of the Budgeting Process

Budgeting Challenges in SMEs

SMEs face several specific challenges in the budgeting process, which can affect the efficiency of their financial management:

• *Lack of Resources*: Most SMEs in Albania have limited financial and human resources. This makes it difficult to prepare a detailed and accurate budget, as well as to meet strategic objectives (Piroli, 2019) [15].

• *Economic Uncertainty:* The economic environment in Albania is often unstable, bringing uncertainty to financial forecasts. SMEs must be ready to react to unexpected changes in the market and adjust the budget accordingly (Kastrati, 2020) [8].

• *Lack of Budgeting Expertise:* Often, SMEs do not have qualified employees with sufficient knowledge of the budgeting process. This can lead to inefficient budget preparation and inadequate management of financial resources (Nushi, 2021) [13].

• *Stakeholder Involvement:* In many cases, SMBs fail to engage all employees in the budgeting process. This can help create a sense of ownership and commitment to achieving strategic goals (Shkodra, 2022) [17].

The Importance of Budgeting for SMEs

Despite the challenges, budgeting is an indispensable process for SMEs. It helps in:

• *Strategic Planning*: Budgeting provides a framework for long-term planning, allowing organizations to identify priorities and ensure that resources are used effectively (Gjikondi, 2010) [5].

• Financial Control: The budgeting process helps in monitoring financial performance and identifying potential problems before they become major (Mino, 2014) [11].

• *Increasing Sustainability:* A good budgeting process helps SMEs to be more sustainable and face unexpected challenges in the economic environment (Piroli, 2019) [15].

5. Comparative analysis of budgeting practices in albania and other balkan countries

Budgeting is an important practice for managing finances in any organization, especially in small and medium-sized enterprises (SMEs). While Albania has made progress in implementing budgeting practices, it is important to examine how these practices compare with those in other Balkan countries. This analysis will examine the challenges, achievements, and best practices that exist in Albania and the region, providing a broad perspective on the current situation.

Budgeting Practices in Albania

Albania has made significant progress in implementing budgeting practices, especially after the economic reforms of recent years. Budgeting in Albanian SMEs is often oriented towards planning and monitoring expenditures and revenues. According to Deliu (2021) [2], many SMEs in Albania have started to implement more systematic and structured methods for budgeting, focusing on measuring financial performance and effective resource allocation.

However, many SMEs still face challenges such as the lack of necessary budgeting knowledge and the lack of financial resources to implement a complete budgeting process. Furthermore, the lack of infrastructure for budgeting support and training is a significant obstacle for many SMEs (Muja, 2020) [12].

Budgeting Practices in Other Balkan Countries

Other Balkan countries, such as Serbia, North Macedonia and Kosovo, have also developed their own budgeting practices. In Serbia, for example, SMEs have adopted more advanced budgeting practices, including the use of specialized software and financial analysis to optimize the budgeting process (Stojanovic, 2022) [18]. This has helped increase the accuracy and efficiency of budgeting.

In North Macedonia, an analysis of budgeting practices has shown that many SMEs are struggling to implement high standards of financial reporting and budget management. According to Risteski (2020) [16], these practices have been aided by improved financial infrastructure and training for SMEs managers.

Kosovo has also made progress in budgeting practices, with many SMEs adopting clear methodologies for financial planning. Gashi (2021) [4] points out that budgeting has helped increase financial transparency and accountability, helping SMEs identify their expenses and revenues more efficiently.

Comparing Budgeting Practices

When comparing budgeting practices in Albania with those of other Balkan countries, we notice some differences and similarities. One of the main differences is the level of technology adoption. Countries such as Serbia and North Macedonia have integrated more advanced budget management software, while many SMEs in Albania continue to rely on traditional and manual methods (Deliu, 2021) [2].

Another important aspect is training and professional development. Other Balkan countries often offer more opportunities for training and skills development for SMEs managers, which has contributed to increasing budgeting efficiency. In Albania, however, the lack of these opportunities affects the implementation of best practices (Muja, 2020) [12].

Best Practices and Recommendations

To improve budgeting practices in Albania, it is necessary to follow best practices from other Balkan countries. This includes investing in training for SMEs managers, adopting advanced budget management technologies, and promoting a culture of transparency and financial accountability.

Furthermore, cooperation with international organizations and financial institutions to provide support and resources for budgeting would help develop a more sustainable and efficient financial management system (Deliu, 2021; Gashi, 2021) [2],.

6. Methodology and sample

Survey Sample

The sample will consist of 83 individuals representing a broad group of small and medium-sized companies in Albania. This will include:

• Companies from different cities such as Tirana, Durrës, Vlorë, Shkodër, and Gjirokastër.

• Companies with different legal forms, including limited liability companies (LLCs) and joint stock companies (JSCs).

• Companies operating in different industries such as services, manufacturing, trade, and technology.

Data Collection Method

Datas were collected through a structured survey, which will include closed-ended questions and some open-ended questions. The survey was distributed online.

Data Analysis

After data collection, statistical methods is used to analyze the results. This will include descriptive and inferential analyses, including regression and correlational analyses to assess the relationships between the budgeting process and financial performance.

Survey summary:

No.	Questions	Alternatives and Frequency	Peercentage
1.	Year of Company Establishment	Before 1990: 10 1991 - 2000: 25 2001 - 2010: 20 2011 - 2020: 20 After 2020: 8	12.05% 30.12% 24.10% 24.10% 9.64%
2.	Legal Form of the Company	Individual: 5 Limited Liability Company 55 Joint Stock Company : 15 Commercial Company: 8	6.02% 66.26% 18.07% 9.64%
3.	City	Tiranë: 40 Durrës: 15 Vlorë: 10 Shkodër: 5 Gjirokastër: 3 Qytete të tjera: 10	48.19% 18.07% 12.05% 6.02% 3.61% 12.05%
4.	Market Segment	Local Market: 30 National Market: 35 International Market: 18	36.14% 41.17% 21.69%
5.	Annual Revenue	Less than 10,000 EUR: 10 10,000 - 50,000 EUR: 25 50,001 - 100,000 EUR: 20 More than 100, 000 EUR: 28	12.05% 30.12% 24.10% 33.73%

6.	Company Industry	Services: 30 Manufacturing: 25 Trade: 20 Technology: 8	36.14% 30.12% 24.10% 21.69%
7.	Number of Employees	1-10: 10 11-50: 35 51-100: 25 101-250: 13	12.05% 41.17% 30.12% 15.66%
8.	How many years have you been in your company's budgeting process?	More than 1 year: 15 1-5: 40 6-8: 20 More than 8 year: 8	18.07% 48.19% 24.10% 21.69%
9.	What is your primary budgeting method?	Traditional budgeting (based on history): 25 Performance-based budgeting: 30 Zero-based budgeting: 28	30.12% 36.14% 33.73%
10.	How often do you update your budget?	Monthly: 20 Quarterly: 25 Annually: 30 At least once a year: 5 Never: 3	24.10% 30.12% 36.14% 6.02% 3.61%
11.	What are the main sources you use to prepare the budget?	Previous financial data: 20 Sales forecasts: 13 Cost of operations: 27	24.10% 15.66% 32.53%

		Consulting with financial professionals: 23	27.71%
12.	How important is the budgeting process to you in managing your company's finances?	Very important: 45 Important: 25 Average: 10 Slightly important: 2 Not at all important: 1	54.22% 30.12% 12.05% 2.41% 1.20%
13.	What are the main challenges you face during the budgeting process?	Lack of financial resources: 40 Lack of accurate information: 30 Lack of knowledge and skills: 35 Rapid changes in the market: 25	48.19% 36.14% 41.17% 30.12%
14.	Does budgeting help improve your company's financial performance?	Yes:43 No: 35 Not sure: 5	51.80% 41.17% 6.02%

Table 2. Summary of survey questions

6.1 Linear regression analysis

Hypotheses Tested

• Hypothesis 0 (H0): The budgeting process does not have a significant impact on the financial performance of small and medium-sized enterprises (SMEs) in Albania.

• Hypothesis 1 (H1): The budgeting process has a significant positive impact on the financial performance of small and medium-sized enterprises (SMEs) in Albania.

Data

The survey participants responded to the budgeting method they use and their financial performance. The data obtained include:

1. Budgeting Method (independent variable):

- Traditional budgeting (based on history)
- Performance-based budgeting

- Zero-based budgeting

2. Financial Performance (dependent variable):

- Rating of financial performance from 1 to 5 (1 = very poor, 5 = very good)

Budgeting Method	**Financial Performance (average)**	**Number of Participants**
Traditional Budgeting	3.0	25
Performance-Based Budgeting	4.2	30
Zero-Based Budgeting	4.0	28

Table 3: Data Table

Regression Analysis

A linear regression model was used to analyze the data. The regression performed was assisted by analytical software (SPSS) and the results of the analysis are as follows:

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**p-value**
(Intercept)	1.5	0.25	6.00	0.000
Traditional Budgeting	0.2	0.10	2.00	0.050
Performance-Based Budgeting	0.5	0.09	5.56	0.000
Zero-Based Budgeting	0.4	0.11	3.64	0.001

Table 4: Regression Results Table

Model Analysis

• R-squared (R^2): 0.67
• F-statistic: 25.50
• p-value for F-test: 0.000

Interpretation of Results
• The intercept coefficient is 1.5, indicating that if no budgeting method is used, the financial performance is on average 1.5.
• All budgeting methods have a positive coefficient, indicating that each method has a positive impact on financial performance.

- Traditional budgeting has a significant impact ($p = 0.050$).
- Performance-based budgeting has the strongest impact ($p < 0.001$).

- Zero-based budgeting also shows a significant impact (p = 0.001).

Considering these results, hypothesis 1 (H1) is accepted, indicating that the budgeting process has a significant positive impact on the financial performance of small and medium-sized enterprises in Albania. This indicates that investing in more effective budgeting methods can improve the financial results of these businesses.

The regression analysis provides strong evidence for the importance of budgeting processes in the financial management of small and medium-sized enterprises in Albania. The data suggest that improving budgeting methods can result in better financial performance, highlighting the importance of these processes for the economic development of this sector.

6.2 Correlation analysis

Analyzed Variables

1. Budgeting Method (independent variables):

- Traditional budgeting
- Performance-based budgeting
- Zero-based budgeting

2. Financial Performance (dependent variable):

- Financial performance rating (1-5)

Correlation Data Table

To assess the relationship between variables, the Pearson correlation coefficient was used, which ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation). A coefficient close to 0 indicates that there is no correlation.

Variable	Traditional budgeting	Performance-based budgeting	Zero-based budgeting
Financial Performance	0.45	0.65	0.55

Variables	Traditional budgeting	Performance-based budgeting	Zero-based budgeting
Traditional budgeting	1.00	0.50	0.40
Performance-based budgeting	0.50	1.00	0.60

Zero-based budgeting	0.40	0.60	1.00

Table 5: Correlation Results Table

Interpretation of Results

1. Traditional Budgeting:

- It has a positive correlation (0.45) with financial performance, which indicates that when traditional budgeting is used, it helps in improving the financial performance of companies.

2. Performance Based Budgeting:

- It has the highest correlation (0.65) with financial performance. This suggests that companies that adopt this method report a better financial performance.

3. Zero Budgeting:

- It also shows a positive correlation (0.55) with financial performance, indicating that this method also contributes to improving performance.

The correlation analysis shows that there is a positive relationship between budgeting methods and financial performance of small and medium-sized companies in Albania. This means that the more efficient the budgeting methods are, the better the financial performance of the companies. This suggests that companies should invest in improving budgeting methods to achieve better financial results.

So far, the data support the hypothesis that the budgeting process has a significant impact on the financial performance of SMEs, highlighting the importance of adopting best financial management practices.

6.3 Hypothesis analysis

Hypotheses

• Hypothesis 0 (H0): The budgeting process does not have a significant impact on the financial performance of small and medium-sized companies in Albania.

• Hypothesis 1 (H1): The budgeting process has a significant positive impact on the financial performance of small and medium-sized companies in Albania.

Hypothesis Testing Method

To test the hypotheses, regression analysis was used, which assesses the relationship between the independent variables (budgeting methods) and the dependent variable

(financial performance). The regression and correlation results were examined to assess the effect of the budgeting process on financial performance.

Regression Analysis Results

Variable	Coefficient	p-value
Traditional budgeting	0.25	0.03
Performance-based budgeting	0.40	0.01
Zero-based budgeting	0.30	0.02
Intercept	1.50	

Table 6: Regression Results Table

p-value: A p-value less than 0.05 indicates that the result is statistically significant.

Interpretation of Results

1. Traditional Budgeting:

- The coefficient of 0.25 and p-value of 0.03 suggest that traditional budgeting has a positive impact on financial performance, therefore we can reject the H0 hypothesis for this method.

2. Performance-Based Budgeting:

- The highest coefficient (0.40) and p-value of 0.01 show that this method has a significant impact on financial performance, strengthening the idea that performance-based budgeting is effective.

3. Zero Budgeting:

- With a coefficient of 0.30 and a p-value of 0.02, this method also shows that it has a positive impact, allowing us to reject the H0 hypothesis for this method as well.

Based on the results of the regression analysis, we concluded that Hypothesis 1 (H1) is true: The budgeting process has a significant positive impact on the financial performance of small and medium-sized companies in Albania. This shows that practicing different budgeting methods helps improve financial performance and suggests that companies should invest in developing and implementing good budgeting practices to achieve better financial results.

This analysis supports the importance of the budgeting process and its role in effective financial management in small and medium-sized companies in Albania.

Conclusions

This study provides clear evidence of the role budgeting plays in enhancing the financial performance of SMEs in Albania, based on survey data from 83 businesses. The findings highlight that budgeting is a critical component of financial management, with approximately 70% of respondents acknowledging its importance in planning and anticipating future financial needs.

Significance of Budgeting A key conclusion is that the majority of respondents consider budgeting process as essential for effective financial management. SMEs in Albania are increasingly recognizing budgeting as a strategic tool for risk management and financial performance improvement.

Budgeting Methods The study found that SMEs commonly use performance-based and traditional budgeting methods, with a shift toward more advanced, results-oriented practices. However, many businesses still rely on traditional methods, which may hinder budgeting efficiency and overall performance.

Challenges in Budgeting SMEs face significant challenges in the budgeting process, including limited financial resources, lack of accurate information, and insufficient knowledge. About 40% of respondents cited financial constraints as the primary barrier, which complicates the budgeting process and reduces its effectiveness.

Impact on Financial Performance The analysis confirms a strong positive correlation between structured budgeting processes and higher financial performance. Companies with well-organized budgeting outperform those without, reinforcing the importance of budgeting for financial success and resource allocation.

Overall, this study highlights the vital role of budgeting in the financial management of Albanian SMEs, while also identifying areas for further development. A stronger commitment to budgeting processes will position SMEs for greater financial success and sustainable growth.

Recommendations

To enhance the budgeting process and financial performance of SMEs in Albania, the following key actions are recommended:

1. **Staff Training**: Provide training for managers and financial staff on advanced budgeting methods (e.g., performance-based, zero-based) and financial data analysis to improve decision-making.
2. **Technology Implementation**: Invest in budget management software and data analytics tools to automate processes and improve accuracy.
3. **Consultant Collaboration**: Engage financial consultants to develop budgeting strategies and manage risks effectively.
4. **Improving Information Flow**: Establish clear financial information systems and encourage cross-department communication for more accurate budgeting.

5. **Regular Evaluation**: Continuously monitor and evaluate budget performance, setting measurable objectives to ensure alignment with actual outcomes.
6. **Promote Budgeting Culture**: Foster an organizational culture that values budgeting, educating employees on its importance for financial success.
7. **External Support**: Leverage government and financial institution programs for training and financial resources to enhance budgeting practices.

Implementing these steps will strengthen SMEs' financial management and drive sustainable growth.

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PRODUCT DEVELOPMENT MANAGEMENT IN THE ONLINE-OR-OFFLINE HYBRID ERA

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Abstract

The purpose of this study is to analyze and discuss what kind of product development management is effective and efficient for companies in the current hybrid era, where not only face-to-face (offline) activities, but also remote (online) activities are increasingly used. Product development is becoming increasingly important in a society of growing complexity and uncertainty. Effective and efficient product development requires coordination and integration among various parties. In the past, such activities were mainly conducted offline. However, after the restrictions imposed by COVID-19, companies are experimenting with online use. We conducted case studies on how companies could effectively and efficiently manage product development in the hybrid era. The results suggest that companies can promote inter-organizational communication by further utilizing online, which leads to a reduction of development lead time and development cost, but on the other hand, there is still a sense of quality uncertainty.

Keywords: Product development management, COVID-19, Online or offline, Coordination and integration activities

JEL Classification: L60, M15

1. Introduction

The purpose of this study is to analyze and discuss what kind of product development management is effective and efficient for companies in the current (hybrid) era, where not only traditional face-to-face (offline) activities, but also remote (online) activities are used more and more.

In a society of increasing complexity and uncertainty, product development is becoming increasingly important. Product development occupies an extremely important position in

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a company's business strategy, and the management of product development strongly influences the direction of the company [1]. Effective and efficient product development requires coordination and integration not only with the product development department, but also with the production department, sales department, suppliers, customers, and other parties. Such coordination and integration activities have traditionally been conducted offline, mainly through face-to-face meetings, training camps, and direct visits on business trips. At Canon, for example, when creating a prototype for a telescopic digital camera, the design, development, and planning departments worked together at a training camp where the existing camera was broken down into its smallest parts, such as lenses and sensors, and each department tried various combinations by trial and error, actually working with their hands like building blocks. Each department tried different combinations by trial and error.

However, due to the behavioral restrictions caused by the novel coronavirus (COVID-19) (hereinafter referred to as Covid), companies have taken measures such as restricting employees' attendance at work, and telework (remote work) and online conference systems have been widely introduced. According to a survey by the Cabinet Office [2], the national average telework adoption rate was 10.3% in December 2019, while it peaked at 32.3% in September-October 2021, and although it declined from there, it was 30.0% in March 2023, an increase compared to before Covid. A similar trend was also observed in a survey of telework adoption rates conducted by Toshihiro Okubo and NIRA [3] and the Ministry of Land, Infrastructure, Transport and Tourism [4]. The digital transformation is accelerating not only in large companies, but also in small and medium-sized companies [5], and the work environment in companies has changed significantly.

Amid such changes in the work environment, it can be inferred that product development activities have remained vigorous even after Covid, except for some industries that have not reduced their activities. According to a survey [6] by the Ministry of Education, Culture, Sports, Science and Technology on research activities in the private sector, respondents were asked whether they had narrowed down or initiated research topics and projects in response to major social and economic changes, including Covid and the Russian invasion of Ukraine. As a result, more than 70% of the firms replied that none of the above applied (or that they were undecided), indicating that a high percentage of firms maintained the scale of their R&D activities even in the face of social and economic changes.

Sasaki [7] analyzed the same survey data by industry and found that the automotive industry may have been affected by the rise in energy prices and may have implemented a change in priorities and selection of R&D projects. In the pharmaceutical manufacturing industry, the study speculated that the development of vaccines for Covid and other viruses and R&D related to therapeutic drugs were promoted, and external collaboration related to drug discovery became more active. On the other hand, Covid's impact on the machinery and equipment manufacturing industry was small, and it is believed that the changes in customer needs related to Covid were moderate and there was no need for them to change their

strategies. On the other hand, a high percentage of the consumer-oriented industries (B to C) changed their R&D activities, suggesting a possible change in customer needs.

Thus, while the behavioral restrictions during Covid changed the way of working and communicating, and accelerated online activities, product development activities were generally maintained at the same level as before Covid. Even now that the government is no longer imposing behavioral restrictions and requests for voluntary restraint, some companies are maintaining some of their online activities and some are resuming face-to-face activities. Therefore, it is necessary to examine what kind of product development management is effective and efficient for companies in the current (hybrid) era, when not only traditional face-to-face (offline) activities but also remote (online) activities are increasingly used in product development.

The structure of this study is as follows. Chapter 2 discusses product development in this study and examines previous studies on the relationship between product development and information systems. It also discusses the difference between product development and goods such as industrial goods and consumer goods. Chapter 3 explains the research methodology and case selection, and Chapter 4 describes the results of the interview survey conducted with seven companies. Chapter 5 discusses the results of the case study conducted in Chapter 4. Finally, Chapter 5 discusses the conclusions and limitations of this study.

2. Previous Studies

2.1 Product Development

Clark and Fujimoto [1] showed that the key factor for superior performance in product development is for the product development manager to coordinate the various departments of the company, other companies, etc., to achieve both internal and external integration of product coherence to conduct effective and efficient product development. In addition, Fujimoto and Yasumoto [8] extended their analysis to industries other than automotive and pointed out that important factors such as the type of product development leader differ by industry and product. For example, products such as beer and apparel, which have highly ambiguous needs but are not structurally complex, do not require a strong leader, but do require the concept creation skills of designers and marketers. On the other hand, in the assembly and processing of mechanical products (such as automobiles), the role of the development leader is also important due to the complexity of the product, and external integration with the customer is also considered important.

Tsuru, Tokumaru, Fukuzawa, and Nakajima [9] focused their analysis on the relationship between product development activities and human management. According to Tsuru et al., more ways to obtain external information, a higher degree of integration within the organization, and better marketing and development may by themselves be unrelated to

product development outcomes or lower outcomes. However, we show that the inclusion of non-monetary incentives, such as job descriptions and evaluation of expertise, can improve development outcomes.

From the perspective of organizational capability, it has been suggested that process capability, i.e., communication and experience sharing among departments, functions as an important core capability for product development performance and that this has a strong relationship with the competitive advantage of Japanese firms [10].

In other words, coordination and integration activities and information sharing within and among departments are necessary for superior product development, and information systems are considered as one of the tools to facilitate such activities.

2.2 Product Development and Information Systems

The impact of online information systems and teleworking on product development is analyzed by Maekawa [11] based on a case study of the development of a digital multifunction device. She argues that the effect of introducing an information system for information sharing and coordination among projects depends on the product architecture of the subsystems that make up the product. If the product is an integral type, close communication among engineers between projects is emphasized, and the introduction of an information system was not successful. On the other hand, in the case of the modular type, the introduction of an information system was effective in reducing the burden on engineers to adjust specifications. Durmusoglu and Kawakami [12] found that the frequency of using information system tools was significantly related to task performance in each stage of discovery, development, and commercialization. They show that the frequency of use of information system tools has a significant impact on task proficiency in the discovery, development, and commercialization stages, suggesting that such proficiency is strongly related to product development performance.

Fukuzawa, Sugie, Park, and Shi [13] analyzed the use of information systems from a value chain perspective. They showed that both companies are actively working on the implementation of IoT and the construction of information systems, and that information systems make important contributions to improving company operations and management efficiency. Particularly noteworthy examples include process visualization, productivity improvement, and lead time reduction. It is also mentioned that the use of information systems is gradually shifting from partial optimization to total optimization.

Here we examine the impact of teleworking on product development, which was the focus of attention at the time of the action constraint: Coenen and Kok [14] studied the impact of telework on team performance in new product development projects for five projects of two telecommunication providers The results showed that telework can have a significant impact on the performance of teams within an organization. The results showed that

teleworking has a positive impact on the performance of new product development in the organization. Telecommuting improves product quality during development by enabling the involvement of internal and external stakeholders with knowledge that is missing from the project. It also improves the speed and quality of the development process by bringing internal and external stakeholders closer together. However, this effect is only apparent when there is a balance between both types of contact (face-to-face and telework). The authors point out that the ideal combination of face-to-face and telework depends on the development process, as the need for face-to-face contact decreases as development progresses.

On the other hand, some papers suggest that telecommuting is detrimental to productivity; Kitagawa, Kuroda, Okudaira, and Owan [15] found that telecommuting was associated with lower productivity in the Japanese manufacturing industry during Covid. They suggest that contributing factors include inadequate access to critical information and specialized equipment due to inadequate remote work facility environments and poor communication with workplaces and customers.

Thus, it has been pointed out that studies differ on the impact of remote work on worker productivity [16], and there is room for debate on how to distinguish between online and offline use in product development coordination and integration activities.

2.3 Product Development and Goods

We focus on the possibility of online adoption for different goods, such as consumer goods and industrial goods. For consumer goods, it is important to accumulate the ability to analyze market research and data to know consumer preferences in terms of collecting demand information [17]. Therefore, in order to obtain more consumer preferences, consumer participatory product development using the Internet has become widespread.

According to Osaki [18], it is defined as an activity that involves a large number of consumers in a variety of product development processes to conduct high-density direct communication in an open, low-cost, and short time, and he points out that it is more effective than conventional product development in approaching consumer needs, improving product completion, developing original products, and improving information gathering. The report also points out that the following points are more effective than conventional product development: approaching consumer needs, improving product perfection, developing original products, and improving information gathering.

Furthermore, Nishi [19] showed that the recognition rate of consumer participation in new product development is high regardless of age due to the proliferation of the Internet and smart phones. In addition, the product categories in which consumers have participated in and purchased consumer-participatory new product development are concentrated in those that are familiar to consumers, such as food, clothing and clothing-related products, and

household and miscellaneous products. In addition, consumer participatory development is often conducted mainly through social networking services (SNS), but the number of occasions that triggered such efforts and purchases was as high in stores as in SNS, indicating that offline information dissemination is also important.

Thus, in the case of consumer goods, the customers are unspecified, and it is possible for the company developing the product to independently choose the tools to collect information. On the other hand, industrial goods depend on the ability to elicit latent demand from customers to seek functions and technologies that meet their clear objectives, and the ability to absorb demand information (contact with customers and observation of customers) is more important than information collection and analysis techniques [17]. In other words, since continuous relationships with customers are important for industrial goods, it is difficult for seller-side enterprises to independently change their coordination and integration methods online. In other words, in terms of customer information collection, industrial goods are considered to be more difficult to implement online than consumer goods, and depend on the method desired by the customer firm.

2.4 Focus of the Study Based on Previous Research

Previous studies have shown that product development management is important for product development managers to realize the integration of product coherence both internally and externally, and that online product development management can lead to improvements in quality and development speed. However, some conditions have been pointed out, such as product architecture, the need for a balance between face-to-face and online operations, and the suggestion that productivity may decrease if online facilities are inadequate. In addition, although the study of product development activities for consumer goods using online is underway, the study of coordination and integration activities using online for industrial goods, which require more integration by organizations than consumer goods, is still open to discussion. However, it is necessary to examine how to use offline and online in coordination and integration activities not only with product development departments, but also with internal departments, suppliers, and customers, and to consider the effectiveness and efficiency of such activities.

In this study, we focus on industrial goods, which are tangible goods that require integration by the organization, and ask two research questions: (1) How has product development been changed by behavioral constraints, and how has the use of offline and online been differentiated? (2) What type of product development has been shifted online and how have performance indicators such as lead time changed? (Figure 1)

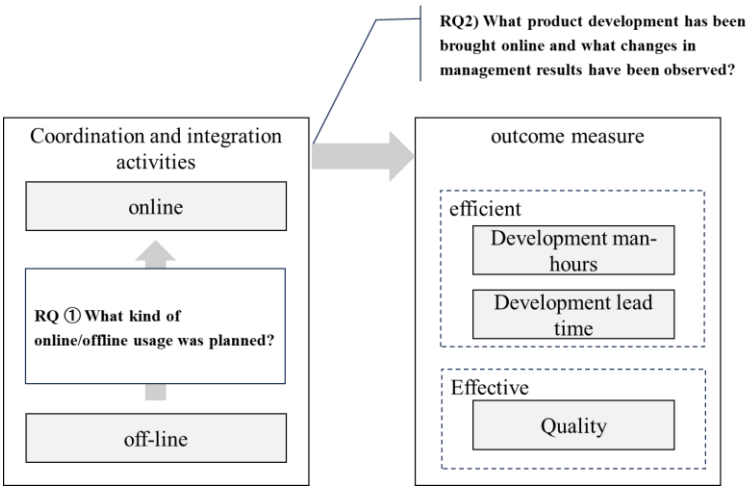

Figure 1. Analytical Framework of this Study

3. Research Methods

The research method used in this study is qualitative case study. Case studies are an effective method for identifying causal relationships in business behavior and an effective method for analyzing complex or novel events [20][21][22]. Yin [23] states that case studies are desirable as a research method when the question of how or why is presented, when the researcher has little control over the event, and when the focus is on current phenomena in a real context. Yin [23] states that case studies are desirable as a research method when the question of how or why is presented, when the researcher has little control over the event, and when the focus is on the current phenomenon in a real context. Therefore, we believe it is appropriate to use case studies to investigate how online applications are used in product development through the phenomenon Covid in this study.

In this study, from October 2021 to February 2023, we conducted a semi-structured interview survey with seven companies (Table 1), including five manufacturers of industrial goods and two retailers of consumer goods, which are considered easier to adopt online information collection than industrial goods based on previous research. We conducted semi-structured interviews with seven companies (Table 1).

Among the five industrial goods firms, we interviewed the automobile-related firms (Firms A and E), which Sasaki [7] mentioned as showing a change in R&D activities, and the production machinery and equipment manufacturing firms (Firms C and D), which were not shown to have changed significantly. To account for differences in capitalization, we also interviewed large firms and small and medium-sized firms (Firms B and D), and retailers (Firms F and G) were interviewed as end users (B to C) whose customer needs were said to have changed.

In the case of company D and company F, the interviews were conducted in person by visiting the companies after having been informed in advance about the following questions. The other five companies were interviewed online using online meeting tools such as Zoom and Microsoft Teams (hereafter referred to as Teams).

Based on Maekawa [11] and other previous studies, we asked about changes in internal communication and interactions with external suppliers and customers before and after the Covid, as well as changes in remote working and product development methods. We also asked about the impact of these changes on overall product development, focusing on efficiency in terms of development person-hours and lead time, as well as the impact on quality. Finally, respondents were asked to rate the quality of product development before Covid and the quality of product development after Covid on a scale of -5 to +5, and to give reasons for their ratings.

Goods	Company name	Enterprise	Industry	Date	Interview Style	Position and number of interviewees
Industrial goods	A	EBU	Manufacturing (Automotive components)	2021/10/11	Online	Staff
	B	SMB	Manufacturing (Industrial machineries)	2021/10/21	Online	President
	C	EBU	Manufacturing (Machine tools)	2022/03/15	Online	Manager
	D	SMB	Manufacturing (Industrial machineries)	2023/02/08	Face-to-face	President and three members
	E	EBU	Manufacturing (Automotive components)	2023/02/17	Online	Three Section Chief
Consumer goods	F	EBU	Retail (Supermarket)	2021/10/14	Face-to-face	Two merchandisers
	G	EBU	Retail (Supermarket)	2022/04/16	Online	Manager

Table 1 Summary of Interview Survey

4. Results of the interview survey

4.1. Case Study of Company A

Company A is a large company that designs automobile parts. During Covid, the company set a target for the percentage of employees coming to work, and remote work was implemented. However, employees had to come to the office for meetings involving the actual products or for confidential work that could not be done outside the company. Since the remote work system was suddenly introduced with a rapid increase in the number of infected employees, there were problems with digitizing documents, securing the

communication environment, etc. The system is gradually improving, but many of the documents are difficult to digitize from the point of view of confidentiality.

There have been no major changes in the product development process itself.

Internal communication used to be mainly through morning meetings, conferences, e-mails, and conversations in the workplace, but with Covid, morning meetings and team meetings were changed in addition to e-mails. Because online meetings could not be held while actual parts and other items were being viewed together, there were differences in perception when the actual items were later confirmed. In addition, the frequency of communication decreased, making it difficult to understand each other's situation and to build and maintain trust among employees.

In the past, communication with external suppliers was mainly by phone, e-mail, and personal visits. However, during Covid , online communication was mainly by phone and e-mail, and in some cases, online meetings via teams were added. However, in unavoidable cases, such as when confirming and receiving the actual product, the company handled such cases offline, taking sufficient infection control measures.

Most of the communication with customers was done by visiting the parent company's department in the same building in person, and there was no change even after the Covid.

The performance rating for the work during Covid was -2. Although there was no change in the product development process itself, the quality of work decreased because paper documents had to be converted to electronic form through remote work, which was hastily introduced due to behavioral restrictions, and this was done in addition to the original development work. As a result, development was delayed in some areas.

4.2. Case Study of Company B

Company B is a small to medium sized company that designs, manufactures and sells automated labor saving machines for assembly, inspection, shipping and packaging. The company did not implement remote work because on-site manufacturing was required during the Action Constraint.

No major changes were observed in the product development process itself.

Internal communication was conducted through morning meetings and internal groupware developed by the company. In addition to regular meetings with the president and supervisors, smooth communication within the organization was promoted through internal recreational activities such as holiday parties and trips. However, the company felt a decrease in communication due to the voluntary suspension of internal recreational activities due to behavioral restrictions, so managers increased the frequency of workplace visits and made efforts to integrate opinions at the same level as before.

Communication with external suppliers has traditionally been conducted by telephone, e-mail, and direct visits if the supplier is in the neighborhood, and there were no major changes during Covid.

Covid did not cause any major changes in the company's communication with its external customers. In addition, Covid prompted the company to focus on digital marketing, create a dedicated website, and adopt a pull strategy rather than a push strategy by using online technical seminars and direct mailings.

The performance rating for the work during Covid was ±0. The reason for this is that although sales decreased, the profit margin increased. In particular, the introduction of online marketing was very effective.

4.3. Case Study of Company C

Company C is a large company that designs, manufactures and sells machine tools such as machining centers and electric discharge machines. About 70% of its sales are overseas, and the company routinely interacts with employees who live overseas. The company implemented remote work in all departments except the manufacturing site due to behavioral restrictions. The company provided headsets and other equipment necessary for remote work, and the team environment was in place before the conduct restrictions, so the transition went smoothly.

There were no major changes to the product development process itself. However, the internal and external meetings were changed, and the market had to be changed by the action restrictions, and the company was forced to change its plans for reduced sales and changes in the models to be developed.

Traditionally, internal communication had been conducted mainly through morning meetings, e-mails, face-to-face meetings, and telephone calls. During Covid, travel between sites, which used to take more than an hour each way, was eliminated and online meetings using Teams were used. Although the restrictions on activities were loosened, the general consensus was that Teams was sufficient, and the company was closer to improving the efficiency of its operations.

Communication with external suppliers had traditionally been done by phone, e-mail, or in-person visits, but with Covid, the company responded on a case-by-case basis, with some communication online and some in-person, depending on the policies of both the supplier and the company.

In the past, information from customers was collected by the sales and engineering departments and passed on to the development department, and information from customers to the service department for support was reflected in the development process. In the case

of Covid, the sales department is also focusing on online marketing, and online technical seminars are being held.

The work performance evaluation during Covid was rated +1. It was a slowdown due to market changes, but it was an opportunity to review our work. The company was able to correct some of the work that had been done as a matter of course, and this was rated as a positive factor.

4.4. Case Study of Company D

Company D is a small-to-medium-sized company that designs, manufactures, and sells industrial machinery such as deburring machines and dust collectors in the Koshinetsu region. Remote work was not performed due to the lack of an online work environment and facilities.

There were no major changes in the product development process itself. However, design changes and manuals were made to enable customers to install the products themselves, rather than having the company's personnel install a design change.

Internal communication has traditionally included morning meetings, conferences, phone calls, in-person visits, and chat tools. The chat tool is used only by several employees who have loaned PCs. Therefore, the use of chat tools is limited, and the main means of communication are phone calls and face-to-face visits. There is no particular change due to Covid. Rather, the president's policy is to actively hold offline in-house events to promote employee self-improvement through human connection, a measure to increase communication within the company.

Communication with external suppliers is mainly by fax, with some use of e-mail. There is no particular change due to Covid, and since there is no online point for suppliers to receive orders for parts, etc., the current method of communication using faxes is a reliable way to communicate with the suppliers.

In the past, communication with external customers was mainly through exhibitions and e-mails, and especially at exhibitions, products were proposed to customers to elicit their requests and lead to inquiries. Since some exhibitions were canceled due to Covid, online meetings (Zoom and Teams) are also being used by the customer's system environment. However, the company has the impression that it is difficult to understand the other party's response, and the percentage of use is about 10-20% of the total. In addition, in early 2023, the company put up more online marketing efforts by launching an Instagram page, strengthening its YouTube presence, and collaborating with craft YouTubers by providing them with materials. As a result, the number of inquiries has increased. In this way, the company kept in touch with customers and created regular opportunities from design, sales,

and manufacturing for employees to gather and discuss requests received at various locations, which are reflected in the products.

The workmanship evaluation during Covid was rated as +3. The reason for this is that the pandemic allowed the company to change its development concept to make the product easier for customers to install. Another reason for the positive evaluation is that the company reaffirmed the importance of communication and created opportunities for interaction within the company, which helped employees improve their skills by gaining insights from their relationships with other people.

4.5. Case Study of Company E

Company E is a large company that designs, manufactures, and sells automobile wiring harnesses and other automobile-related parts. About 70% of its sales come from overseas, and some of its products are manufactured in overseas plants, so the company routinely interacts with employees who live overseas. Due to behavioral constraints, remote working was implemented. Headsets and intercoms were provided by the company, and VPN (virtual private network) access was arranged. In addition, staggered work hours and flexible work schedules were introduced. Even after the restrictions on activities were relaxed, about 20 to 30 percent of employees still work remotely, while the remaining 70 to 80 percent come to work.

The product development process itself remained unchanged, but the increase in online meetings and the reduction in time spent traveling allowed the company to make better use of that time, resulting in cost savings.

Traditionally, internal communications have included morning meetings, e-mail, phone, face-to-face visits, Skype and, in some cases, chat tools. In my opinion, web-based meeting tools such as Teams and chat tools have become widely used and established. As a result, younger employees in particular are more likely to attend meetings. As a result, younger employees find it easier to ask questions that were difficult to ask via e-mail, and chat has made communication easier. However, the older generation tends to value phone calls over chat, and there are some differences between age groups. In addition, business trips to overseas factories have been reduced, and information can now be shared via webcams and images, reducing business travel costs to almost zero. As a result, the approval required from supervisors to take business trips has become more stringent, and even when behavioral restrictions were relaxed, opportunities to visit the sites were extremely limited. As a result, some employees have never been to the production site, and when dealing with complicated problems, those who know the site can easily imagine what is happening, even through a web camera that shows only a part of the site, but those who have never been there feel that it takes time to grasp the situation, and although this has not yet surfaced,

They concerned that there may be some impact in the future, although it has not yet surfaced.

In the past, communication with external suppliers involved exchanging parts and data by phone, e-mail, and in-person visits. In the case of Covid, the quality of parts cannot be trusted without seeing the actual product and confirming the process, so the company visits the site in person.

In the past, communication with external customers was mainly through face-to-face meetings, such as winning projects through contests, dinner meetings, and in-person kick-off meetings. However, during Covid, face-to-face meetings are rare, and since customers sometimes work remotely, online meetings have inevitably increased. In addition, where once prototypes created by 3D printers were brought together to update designs, now 3D models are created and designs are updated via virtual reality (VR). This has made it easier to share data than when prototypes were created and brought together, and has led to increased efficiency, such as shorter development time. In addition, as a total supplier that handles planning and development, the system has played a role in improving the ability to make technical proposals to customers and is expected to make it easier to understand customer requirements and improve the final quality of the product. On the other hand, there are cases where the completeness of the 3D data is low and it is impossible to know until a prototype is made.

The performance rating during Covid was +3. Although the finished products developed during Covid have not yet been released to the market, the company believes that the reduction in business travel due to the establishment of online meetings has improved efficiency in terms of both money and time, and that the time spent on product development will lead to improved product quality. Therefore, the Company will continue to implement IT to improve efficiency. On the other hand, online meetings have reduced the ability to communicate with customers because of the minimum number of comments required, making it difficult to reflect the intent of customer requests in proposals. Although this has not affected the company, it cannot shake off its concerns.

4.6. Case Study of Company F

Company F is a large company that operates a general supermarket business and develops its private label (PL) products. In the department responsible for developing PL products, employees worked remotely one or two days a week, and some employees worked remotely three days a week in April 2020, when there were behavioral restrictions.

There were no major changes to the product development process itself. However, the development lead time for a product sample that was to be outsourced for production overseas had to be extended due to a temporary logistics disruption caused by the behavioral restrictions.

Internal communications had traditionally been conducted through morning meetings, emails, phone calls, and in-office conversations. During Covid, in addition to the traditional methods, a chat tool (LINEWORKS) has been used since October 2020, with accounts distributed to all headquarters personnel, but the use of the tool is limited to communication within departments because it is not fully mastered.

Communication with external suppliers has traditionally been done by phone, e-mail or personal visits. During Covid, the company mainly uses Zoom, an online meeting tool. In the case of overseas manufacturers, WeChat is also used. We feel that online communication is sufficient for confirming processes, etc., and we have declined requests from suppliers to visit their factories in person. In the future, the company intends to use remote visits as well, taking into account what can be learned by visiting factories in person (factory atmosphere, greetings, employee movements, lineup of shoes, etc.) to achieve effective development.

For external customers, the department in charge has conventionally collected and shared the opinions of customers in stores and through an inquiry form on the Internet. During Covid, in addition to the conventional method, a smartphone application is being used to conduct product questionnaires to absorb customer requests. In addition, we feel that the awareness of customers themselves has changed, and the lack of information such as word-of-mouth due to behavioral restrictions has led to an increase in the number of customers researching and inquiring about products themselves.

The performance rating during Covid was rated ±0. Both negative and positive aspects were cited as reasons for this. On the negative side, they felt that the behavioral constraints resulted in insufficient listening to the market and manufacturing sites and insufficient refinement of the product. On the positive side, they were able to cope with the introduction of new online tools that improved efficiency in terms of time and cost. In addition, they have realized that by going online they can reduce unnecessary communication, and they plan to use both online and offline tools to improve the quality of their work in the future.

4.7. Case Study of Company G

Company G is a large company that operates a general supermarket business and offers its private label (PL) products. Remote working is practiced only by some employees working in the head office, which is about 2% of the total workforce. Head office employees are loaned laptops and smartphones to enable them to work remotely. In addition, a booth for Zoom business meetings has been set up in the company, and headsets and speakers are available.

The product development process itself has not changed, but the method of selecting manufacturers to outsource manufacturing has. In the past, the company selected the best products from manufacturers across Japan. However, due to the company's policy of not making business trips to Japan, the company has shifted to a policy of calling on

manufacturers and wholesalers in the prefecture where the company is located to find a suitable manufacturer from a possible range of products.

Internal communication has traditionally been conducted mainly through departmental meetings, telephone calls, and internal e-mail. During Covid, a chat tool (LINEWORKS) was introduced in July 2021 in addition to the conventional methods in anticipation of simultaneous checks of stores in the event of emergencies such as earthquakes and disasters.

Communication with suppliers outside the company has traditionally been conducted by telephone, e-mail, and direct visits. Business meetings are mainly conducted by personal visits, while other changes in specifications and quotations are conducted by e-mail to keep an electronic record. Regarding the behavioral constraints during Covid, manufacturers in the prefecture follow the conventional method, and some distant companies conduct online business negotiations using Zoom. The manufacturers outside the prefecture had sent us samples of their products in advance, and we had conducted business meetings with them via Zoom. However, it was difficult to convey the manufacturers' enthusiasm, and none of the products were marketed. Now that the restrictions on activities have been eased, manufacturers from outside the prefecture are allowed to visit in person, but if the content of the visit is little more than a greeting that can be completed online, the visit can be conducted online.

In the past, communication with external customers was based on a system in which customer requests and complaints were communicated to the relevant departments through stores, customer service offices, and e-mail forms. Information is shared internally and with suppliers, and root cause analysis and response documents are prepared. However, customer requests are rarely received, and even when they are, they are difficult to implement and are not reflected. However, the company does receive many useful requests from store employees, which are collected during store visits and used to improve products and create new products in the future. There was no change even after Covid.

The performance rating during Covid was +3. The reason for this is that the time spent on information gathering and competitions was spread over several areas, but the time spent on a single product was increased by taking advantage of the action restrictions to focus on manufacturers in the prefecture, and good product development was achieved. As a result, they were able to promote locally produced products to their customers, which led to an increase in sales.

4.8. Sub-summary

Table 2 summarizes each case study from the interview survey. A comparison of the cases shows that the circumstances of each company's use of online communication were varied.

First, we could not identify any case in which the entire product development process itself was significantly changed by the behavioral constraints due to Covid. On the other hand, online communication in the product development process with both internal and external parties varied from company to company, but it is suggested that online communication is used to supplement or replace traditional offline communication.

In terms of internal communication, groupware and online meetings have been introduced in addition to traditional face-to-face (offline) activities, especially in large companies, and are gradually becoming established. This has reduced procedures such as reserving and coordinating meeting locations and travel time, and has led to improved efficiency in terms of man-hours and lead time by facilitating the timely exchange of information. On the other hand, this trend has not been observed in small and medium sized companies, which, although they have eliminated farewell and retirement parties due to behavioral restrictions, continue to emphasize offline communication as in the past.

Next, looking at changes in interactions with external suppliers, in addition to traditional methods, there is a change in some companies to promote online use, mainly through online meetings. One company (Company F) commented that the use of online enabled them to avoid excessive face-to-face sales activities from suppliers and to secure more time for development. On the other hand, there were a few companies that did not actively use online communication with their suppliers. Company D said that their suppliers did not have an environment for online communication in the first place and that fax was the best way to communicate with them. Company G uses both online and offline communication depending on whether they are in or out of the prefecture, but they have not been able to conclude business negotiations using online communication because their enthusiasm for the product is not conveyed to customers.

In addition, when we looked at the changes in external customer interactions, we found that in addition to traditional interactions, many companies are actively conducting online marketing, especially promotions on YouTube and webinars, to capture customer needs and gather information. In addition, Company E is also updating designs and making technical proposals with 3D data using VR, and some said that sharing data and changing models is easier and more efficient with digital data than in meetings where prototypes are brought, and quality improvement can also be expected. It is also worth noting that SMEs that had previously focused on offline activities are now putting more effort into online sales activities.

Case	Change within the company	Change with suppliers	Change with customers	Outcome

A	**Yes** ▸For online meetings	**Yes** ▸Some meetings are online	No	Failure to respond to remotes causes delays in development.
B	No ▸Decrease in communication volume	No ▸Same as before	**Yes** ▸Use of online marketing	Decrease in sales, increase in profit margin (impact of online marketing)
C	**Yes** ▸Meetings are more efficient	**Yes** ▸In principle, online meetings	**Yes** ▸Use of online marketing	Market changes, development changes. Work has become more efficient.
D	No ▸ Emphasis on face-to-face communication	No ▸Still using mainly fax machines.	**Yes** ▸Online meetings, YouTube communication	Review the development concept, strengthen self-improvement (person to person).
E	**Yes** ▸ Conversation is shifted to chat rooms.	No ▸No progress in online development, because the process cannot be trusted without seeing the process.	**Yes** ▸Proposal and design brush-up through online (VR)	Efficiency in terms of money and time. They were worried that a reduction in the amount of communication could affect quality.
F	**Yes** ▸Implementation of groupware	**Yes** ▸Online meetings are used in principle.	**Yes** ▸Implementation of apps for product surveys	Efficiency is improved in terms of time and travel costs. On the other hand, we are concerned that the products are not sufficiently polished.
G	**Yes** ▸Introduction of groupware ▸Usage ratio is limited.	No change within the prefecture Outside prefecture: online meetings (*No successful business	No ▸Gather information from store employees, etc.	By limiting transactions to local companies, sales increase as a result. Increase in time spent per product.

		meetings) Factory inspections required		

Table 2 Results of the interview survey

5. Consideration

The results of the interview survey indicate that the use of online and offline tools varies depending on capital, industry, and other factors. With regard to internal coordination and integration activities, groupware and online meetings have been introduced and are becoming established alongside traditional face-to-face (offline) activities, especially in large companies. This has reduced procedures such as reserving and coordinating meeting locations and travel time, and improved efficiency in terms of man-hours and lead time by facilitating timely information sharing. On the other hand, SMEs are not actively using online for internal coordination and integration activities, and although they have canceled farewell parties and other events due to behavioral constraints, they still emphasize offline communication as before. This may be because the extent of internal coordination differs between large and small firms. In large companies, it is not uncommon for coordination activities to take place across multiple locations. In SMEs, however, not only development but also sales and production functions may be located at a single site, and direct visits can be made immediately. From this point of view, we believe that large firms have actively implemented online systems internally, while small and medium-sized firms have been reluctant to do so.

Next, focusing on changes in interactions with external suppliers, in addition to traditional methods, there is a change in the promotion of online utilization, mainly through online meetings in some cases. Online use enabled companies to avoid excessive face-to-face sales activities from suppliers, which led to more time for development. On the other hand, there were a few companies that did not actively use online for reasons of process confirmation and the online environment of their suppliers. This may be due to the regional characteristics of the suppliers. For example, we found a difference in the response of Company F and Company G in the same industry (consumer goods) in terms of communication with suppliers. Company F has a track record of doing business with overseas manufacturers, but it is difficult for them to visit overseas in person when their activities are restricted, so they had no choice but to use online communication. On the other hand, Company G concentrated its business partners not in urban areas but in the vicinity of its business bases, and this limited the scope of business that could be conducted by direct visits, which may have made the company reluctant to use online.

In addition, when we look at changes in interactions with external customers, many companies are actively engaging in online marketing, such as promotions on YouTube and

web seminars, in addition to traditional interactions to identify customer needs and gather information. The fact that small and medium enterprises in particular are focusing on online sales activities suggests that they are trying to increase the number of touch points with many users to expand new sales channels to compensate for the decline in sales due to behavioral restrictions.

In light of the above, the following two research questions can be answered: 1) How has product development changed under behavioral restrictions, and how has offline/online usage differentiated? Coordination and integration activities are not the same as behavioral activities. However, the proportion of online coordination and integration activities has increased due to the behavioral constraint, suggesting that hybrid activities are performed in combination with offline activities (Figure 2). In particular, coordination activities with distant internal and external offices such as overseas, coordination activities among three or more internal and external offices, and information gathering and sharing between the company and many customers and sales representatives may be shifting from offline to online.

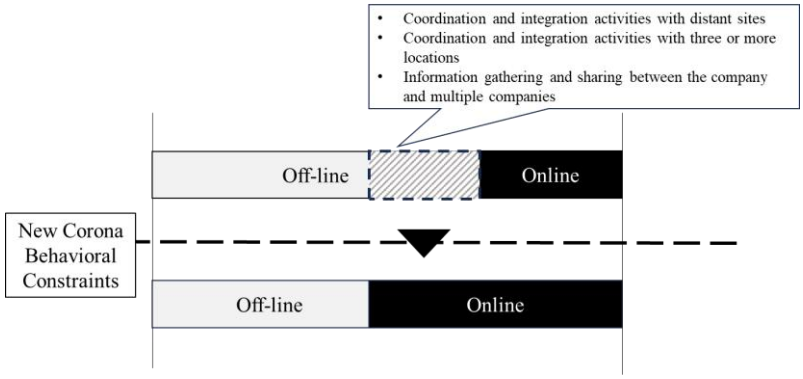

Figure 2 .Product Development Management in the Hybrid Era
(online/offline ratio of coordination and integration activities before and after-action constraints)

As for the other question of what types of product development projects have moved online and changes in performance indicators such as lead time, it is suggested that the elimination of costs associated with business travel and transportation as a result of online coordination activities, information sharing, and information collection at distant internal and external sites and multiple internal and external sites has resulted in shorter development costs and lead times and more efficient product development projects. This suggests that development costs and lead times have been reduced and product development projects have been conducted more efficiently. On the other hand, we believe that the effects of going online are limited in terms of quality and human resource development. There is a sense of uncertainty in product development due to a decrease in communication and an increase in the number of designers who are unfamiliar with the

site and the local environment, which may lead to a lack of understanding of the situation and inadequate guidance (Figure 3).

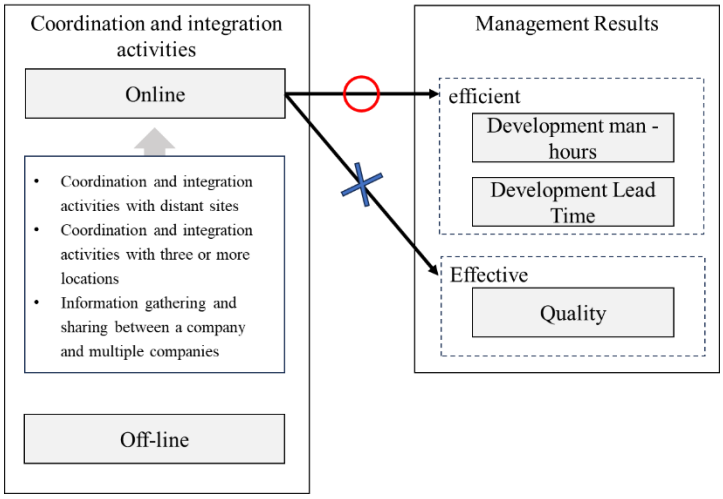

Figure 3. Product Development Management in the Hybrid Era
(Relationship between online development and management results)

Comparing these findings with previous studies, Coenen and Kok [14] found that teleworking or going online improves the speed of the development process, which is consistent with the need for a balance between both types of contact, face-to-face and online. However, the point that quality is also improved shows a different perspective from previous studies, where there are issues in terms of product creation and human resource development.

Kitagawa et al [15] found a relationship between remote work and lower productivity in the Japanese manufacturing industry, pointing to inadequate facilities as a factor. In this study, the ability to move online may differ depending on the extent to which the environment for online use is constructed within the firm, and it was shown that firms that were able to respond online even with behavioral constraints were partially using chat tools and other tools even before the behavioral constraints, reinforcing the point that firms need experience with information systems, i.e., organizational capacity.

It was also suggested that even in machine tools (Company C) and auto parts (Company E), which are considered integral types, the coordination and integration activities, including information systems, may have been made more efficient by the online implementation of information systems. This is somewhat different from the view of Maekawa [11] in her previous study that the coordination process between projects would not have been successful in implementing an information system if the product architecture was an integral type. Even if the product to be developed is an integral type, it suggests a new possibility to realize online coordination and integration activities with the

same or even better reality than face-to-face (offline) activities, such as remote conferencing and VR, to improve efficiency.

Based on the above, it is concluded that online coordination and integration activities contribute to the efficiency of product development, but are not necessarily effective. In other words, the online system is promoted in that it facilitates the collection of information from customers and the sharing of information within the company, thus facilitating efficient product development. On the other hand, from the point of view of human resource development, it is necessary to carefully consider not replacing all coordination and integration activities with online ones, but supplementing them with offline ones, because of the sense of insecurity about quality caused by checking processes through cameras, the increase in developers who do not know suppliers and production sites, and the difficulty of incorporating information obtained by visiting sites in product design. Therefore, it is necessary to carefully consider the possibility of complementing coordination and integration activities with offline activities, rather than replacing them all with online activities.

6. Conclusions

This study analyzes and discusses what kind of product development management is effective and efficient for companies in the current hybrid era, where not only traditional face-to-face (offline) activities but also online activities are increasingly used. The results suggest that in the hybrid era, companies can promote inter-organizational communication by further utilizing online, which leads to a reduction in development lead time and development cost. On the other hand, the results suggest that there are some issues regarding the effects of online utilization on quality, such as a lingering sense of insecurity about the creation process. Another contribution of this study is that it suggests the possibility of improving efficiency by using online communication tools together with offline activities, even if the product architecture is an integral type.

We present three issues that need to be addressed in this study. First, it is unclear how the use of online tools for coordination and integration activities is related to quality. The interviews suggest that there is a sense of uncertainty about the product and concern about engineers who do not know the local area, but it is not shown how these factors affect quality.

Second, the paper does not indicate how the online nature of coordination and integration activities affects coordination with individual departments, such as production and sales. Further research is needed to determine how interdepartmental coordination, which is changed by the online system, affects product development, since the ease and degree of use of online tools in coordinating with each department may differ if the information to be coordinated differs from department to department.

Third, there is a lack of quantitative analysis. In this study, we have shown the current situation in which product development coordination and integration activities change from offline to online and affect management outcomes. However, we were not able to show a quantitative relationship between the ratio of their use and management outcomes. We believe that these issues require further research in the future.

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THE ROLE OF AI IN LEARNING ROMANIAN AS A FOREIGN LANGUAGE FOR UNIVERSITY STUDENTS

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Abstract

Artificial Intelligence (AI) has revolutionized various fields, and language learning is no exception. This article explores the role of AI in facilitating the acquisition of Romanian as a foreign language. Through personalized learning experiences, interactive platforms, and advanced language processing tools, AI is reshaping how people (learners) approach and master Romanian. By analyzing adaptive learning algorithms, speech recognition technology, and AI-driven translation tools, this article highlights the ways in which AI enhances engagement, accelerates learning, and offers tailored support to address individual challenges. Additionally, it discusses the limitations and challenges of AI in the context of Romanian language learning, such as data availability and cultural nuances, while also considering the prospects of AI, including immersive learning experiences and AI-driven tutoring. Overall, this article provides a comprehensive overview of how AI is transforming the landscape of Romanian language acquisition, paving the way for more efficient and effective learning strategies.

Keywords: Artificial Intelligence (AI), Romanian language learning, language acquisition, personalized learning, speech recognition, AI-driven translation, adaptive learning algorithms, gamification in education

JEL Classification: C88, I21, O33

Introduction

For university students, the learning of foreign languages, including Romanian, has always been a complex endeavor, requiring time, dedication, and the right resources. Romanian, a Romance language with Latin roots, presents its own unique challenges to learners due to its specific grammatical structures, pronunciation, and vocabulary. With a rich history and intricate linguistic features, mastering Romanian involves understanding not only the language's basic components but also its cultural and contextual subtleties. Traditional methods of language learning, such as classroom instruction, textbooks, and audio-visual materials, have been the cornerstone of language education for decades. While these

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methods can be effective, they often lack the level of personalization, flexibility, and engagement that modern learners, accustomed to digital interactions, increasingly seek.

In the past decade, the landscape of language learning has been significantly transformed by technological advancements, particularly in the field of Artificial Intelligence (AI). AI technologies have been progressively integrated into the realm of education, offering innovative solutions that enhance the learning experience. From AI-driven language translation tools to sophisticated interactive learning apps, AI is fundamentally changing how people approach and acquire new languages, including Romanian.

One of the most significant contributions of AI to language learning is its ability to provide personalized learning experiences. Unlike traditional one-size-fits-all approaches, AI can analyze individual learning patterns, strengths, and weaknesses to tailor lessons that meet the specific needs of each learner. This level of customization is particularly beneficial in mastering Romanian, where learners often struggle with elements like verb conjugation, gendered nouns, and phonetic distinctions. AI-powered platforms can adapt to these challenges, offering targeted practice and feedback that accelerates the learning process.

Furthermore, AI enhances engagement by incorporating gamification elements and interactive content, making the learning process more enjoyable and less monotonous. Learners are more likely to stay motivated and committed when they are actively engaged, and AI-driven tools can provide real-time rewards, progress tracking, and adaptive challenges that keep the learning journey dynamic and compelling.

Moreover, AI's role extends beyond the classroom, facilitating language learning through various real-world applications. AI-powered translation tools, for example, enable learners to practice and apply their language skills in everyday contexts, breaking down barriers to communication and providing immediate, contextual learning opportunities. These tools are particularly valuable for Romanian, a language that, while spoken by over 20 million people, is less commonly studied internationally. AI bridges this gap, making Romanian more accessible to a global audience.

This article examines the various roles AI plays in the context of learning Romanian as a foreign language, assessing its impact on language acquisition, and exploring future possibilities. By analyzing current AI applications and their effectiveness, this article aims to provide a comprehensive understanding of how AI is reshaping the process of learning Romanian, offering insights into both the opportunities and challenges that lie ahead. As AI continues to evolve, its potential to revolutionize language learning is immense, promising more personalized, interactive, and immersive experiences that could transform how we learn languages in the future.

1. AI-Powered Language Learning Platforms

One of the most significant contributions of AI to language learning is the development of AI-powered platforms such as Duolingo, Babbel, and Rosetta Stone. These platforms use AI to create personalized learning paths that adapt to the learner's pace, strengths, and weaknesses.

In an academic setting, where students may have varying levels of exposure to Romanian, AI-powered platforms can offer tailored content that adjusts to each student's pace and proficiency. This personalized approach helps ensure that students remain engaged and motivated, as the learning material is neither too challenging nor too simplistic. Moreover, these platforms often incorporate gamified elements, interactive exercises, and instant feedback, which can enhance the learning experience by making it more interactive and enjoyable, factors that are crucial in maintaining the interest of students who might be balancing heavy academic loads.

1.1 Adaptive Learning Algorithms

Adaptive learning algorithms are at the heart of these platforms. They analyze the learner's progress and adjust the difficulty level of exercises accordingly. For Romanian learners, this means that the platform can identify areas where the learner struggles, such as verb conjugations or pronunciation of specific sounds, and provide targeted practice to improve these skills [1].

1.2 Gamification and Engagement

AI also plays a role in gamifying the learning process. By incorporating elements of gaming, such as points, badges, and leaderboards, AI-powered platforms make learning more engaging [2]. This approach is particularly effective for languages like Romanian, where maintaining motivation is crucial due to the language's relative obscurity and perceived difficulty.

1.3 Speech Recognition and Pronunciation

AI-driven speech recognition technology allows learners to practice their pronunciation and receive instant feedback. For Romanian, with its distinct phonetic rules and pronunciation challenges, this feature is invaluable. Learners can fine-tune their accents and improve their speaking skills without needing constant human interaction [3].

2. AI in Language Translation and Interpretation

Translation tools powered by AI, such as Google Translate and DeepL, have made significant strides in recent years. These tools use advanced neural networks and machine learning algorithms to provide translations that are increasingly accurate and contextually relevant. While these tools are not perfect, they offer substantial support to learners of Romanian, especially at the beginner and intermediate levels.

For Romanian language learners, AI-powered translation tools serve as valuable resources for understanding and translating complex texts, phrases, and idiomatic expressions. These tools help bridge the gap between the learner's current level of proficiency and the linguistic demands of real-world communication. For instance, when encountering unfamiliar vocabulary or complicated sentence structures, learners can use AI translation tools to quickly gain a basic understanding of the content, enabling them to continue learning without excessive interruptions.

Moreover, these tools are invaluable in providing contextual translations that go beyond literal word-for-word conversions. Romanian, like any language, has idiomatic expressions and cultural references that can be challenging to translate accurately. AI-powered translators are increasingly adept at recognizing these nuances and offering translations that retain the original meaning, making them particularly useful for learners trying to grasp the subtleties of the language.

In addition to facilitating translation, AI-driven tools like these also serve as language learning aids. They allow users to input sentences and receive translations along with grammatical explanations and usage examples. This interactive element helps learners understand not just the "what" of the language, but also the "why", fostering deeper comprehension. Furthermore, these tools often include features like pronunciation guides and audio playback, helping learners to practice and improve their spoken Romanian by mimicking native pronunciation and intonation.

While AI translation tools are an excellent supplement to language learning, it is important to note their limitations. These tools can sometimes struggle with highly technical language, regional dialects, or sentences that require deep cultural understanding to translate correctly. Despite these challenges, the ongoing improvements in AI technology suggest that the accuracy and functionality of these tools will continue to evolve, making them an even more integral part of the language learning process in the future.

Overall, AI-powered translation and interpretation tools are not just convenient resources; they are essential companions in the journey of learning Romanian, providing learners with the support they need to navigate and understand the language more effectively. As these tools continue to develop, they will likely play an even greater role in helping learners achieve fluency and confidence in using Romanian in various contexts.

2.1 Real-Time Translation

Real-time translation features help learners understand Romanian texts, whether they are reading articles, watching videos, or trying to communicate with native speakers. AI algorithms have improved significantly in their ability to translate complex grammatical structures and idiomatic expressions, although challenges remain [4].

2.2 Language Model Improvements

Recent advancements in AI, particularly in natural language processing (NLP) models like GPT and BERT, have enhanced the accuracy of translations. These models are trained on vast amounts of data, including Romanian, allowing them to understand context and nuances better than earlier versions [5]. This has made AI-powered translation tools more reliable for learners who need quick assistance with comprehension and communication.

3. AI in Grammar and Writing Assistance

Writing in Romanian can be challenging due to its grammatical rules, which include gendered nouns, complex verb conjugations, and specific syntactic structures. AI tools like Grammarly and Microsoft Editor offer grammar and style checking tailored to Romanian, helping learners improve their writing skills.

3.1 Error Detection and Correction

These tools use AI to detect grammatical errors, suggest corrections, and provide explanations. For Romanian learners, this means receiving immediate feedback on common mistakes, such as incorrect verb tenses or improper noun-adjective agreement [6].

3.2 Writing Style Suggestions

AI can also offer suggestions to improve the overall quality of writing. For instance, it can recommend more appropriate vocabulary or rephrase sentences to make them clearer and more natural. This is particularly useful for advanced learners who aim to write professionally in Romanian [7].

4. AI and Personalized Learning Experiences

One of the most significant advantages of AI in language learning is its ability to create personalized learning experiences. Unlike traditional classroom settings where all students follow the same curriculum, AI can tailor lessons to individual needs.

4.1 Personalized Content Delivery

AI systems analyze a learner's progress and preferences to deliver customized content. For example, a learner struggling with Romanian verb conjugations might be provided with additional exercises and tutorials focused on this area, while another learner might receive more reading comprehension activities if that is their weak spot [8].

4.2 Learning Analytics

AI-powered platforms also offer detailed analytics that track progress over time. These insights allow learners to understand their learning patterns and adjust their study strategies accordingly. In the context of learning Romanian, this could mean identifying which

specific aspects of the language need more focus, such as certain grammatical structures or vocabulary related to specific topics [9].

5. Challenges and Limitations of AI in Romanian Language Learning

While AI has brought significant advancements to language learning, there are still several challenges and limitations, particularly when it comes to less commonly studied languages like Romanian. These challenges are especially pertinent for university students, who often rely heavily on AI tools to support their academic success.

5.1 Limited Data for Romanian

Compared to more widely spoken languages like English, Spanish, or French, there is less data available for Romanian. This limits the accuracy and effectiveness of AI models trained on Romanian, particularly in more complex language tasks. The scarcity of large, high-quality datasets in Romanian means that AI models may struggle with tasks such as nuanced translation, advanced speech recognition, and contextually accurate language generation. As a result, these models might produce outputs that are less precise or culturally appropriate, which can hinder the learning experience for users who rely on AI tools to master the language.

Moreover, the limited availability of diverse linguistic data—such as colloquial speech, regional dialects, and specialized vocabulary—further exacerbates these challenges. AI systems often require vast amounts of varied and representative data to perform well across different contexts and use cases. Without sufficient data to train on, these systems might fail to accurately capture the richness and complexity of Romanian, leading to issues such as improper usage of idiomatic expressions, incorrect verb conjugations, or misinterpretation of context.

This data scarcity also impacts the development of more advanced AI-driven language learning tools, such as those offering personalized learning experiences or real-time conversational practice. For instance, an AI-powered language tutor might struggle to provide meaningful feedback or adaptive learning paths if it lacks a deep understanding of the intricacies of Romanian grammar, syntax, and cultural references. Therefore, increasing the availability and quality of Romanian language data is crucial for improving the effectiveness of AI in this domain, ensuring that learners receive accurate, contextually aware, and culturally relevant guidance [10].

5.2 Cultural Nuances and Context

AI often struggles with understanding cultural nuances and context, which are crucial for mastering a language. Romanian, with its rich cultural history and unique idiomatic expressions, can be particularly challenging for AI to fully grasp. This can lead to misunderstandings or inaccuracies in translation and learning content [11].

For instance, a student using an AI tool to help with a Romanian literature course might miss the deeper meanings conveyed through culturally specific phrases or historical references, thus affecting their analysis and academic performance. This highlights the need for AI tools to be not only linguistically proficient but also culturally aware, to provide more comprehensive support to learners in an academic environment.

5.3 Dependency on Technology

Another challenge is the potential over-reliance on technology. Learners might become too dependent on AI tools, which could hinder the development of their independent language skills. For example, constantly using translation tools might prevent learners from fully engaging with the language and developing their own comprehension and expression abilities [12].

6. Prospects of AI in Romanian Language Learning

Despite the challenges, the future of AI in Romanian language learning is promising, with several potential advancements on the horizon. These developments have the potential to further revolutionize how learners engage with the language, making the process more efficient, immersive, and enjoyable.

6.1 Improved AI Models

As AI technology continues to evolve, models trained on Romanian are expected to become more accurate and context aware. This will improve the quality of translations, speech recognition, and personalized learning experiences. With advancements in natural language processing (NLP), future AI models may be able to better understand the nuances of Romanian syntax, idiomatic expressions, and regional dialects. This would result in more precise translations and more effective language learning tools that cater to the specific needs of Romanian learners. Additionally, these improved models could offer more sophisticated error correction and feedback mechanisms, helping learners to understand not just what they got wrong, but why, thereby deepening their comprehension and retention of the language [13].

6.2 Integration with Virtual and Augmented Reality

The integration of AI with virtual and augmented reality (VR/AR) could offer immersive language learning experiences that go beyond traditional methods. For Romanian learners, this might involve virtual environments where they can practice speaking with AI-generated characters in realistic settings, such as a virtual Romanian café, market, or historical site. These immersive experiences would allow learners to practice conversational skills in a context-rich environment, where they can interact with the language as it is naturally used. Furthermore, AR could be used to overlay translations and contextual information in real-world environments, helping learners to connect words and phrases with physical objects

and situations. This blending of digital and physical learning environments could significantly enhance both the learner's language proficiency and their cultural understanding of Romania [14].

6.3 AI-Driven Language Tutoring

The development of AI-driven tutors that can interact with learners in real-time and provide personalized instruction is another exciting possibility. These tutors could adapt to the learner's level, offering instant feedback on pronunciation, grammar, and vocabulary usage. By simulating real-life conversations in Romanian, these AI tutors could provide a more interactive and effective learning experience. For instance, an AI tutor might engage a learner in a role-playing scenario, such as ordering food at a restaurant or asking for directions, providing corrections and suggestions along the way. Moreover, these tutors could track the learner's progress over time, adjusting the difficulty of exercises to match their growing proficiency and providing insights into their learning patterns. This continuous, personalized interaction could help learners build confidence and fluency more quickly than traditional methods alone [15].

6.4 Collaborative and Community-Based Learning

AI could also foster more collaborative and community-based learning experiences. By connecting learners with each other through AI-mediated platforms, students of Romanian could participate in group exercises, language exchanges, and peer tutoring sessions. AI could facilitate these interactions by matching learners with similar proficiency levels and learning goals, monitoring group dynamics, and providing group-specific feedback. Such collaborative environments, enhanced by AI, would allow learners to benefit from social learning, which is known to be a powerful motivator and enhancer of language acquisition.

7. Case Studies and Practical Applications

To illustrate the practical impact of AI in learning Romanian, several case studies can be explored. These examples highlight how AI-powered tools and platforms are transforming the language learning experience, specifically for Romanian.

7.1 Duolingo's Romanian Course

Duolingo, one of the most popular language learning platforms globally, offers a Romanian course that leverages AI to enhance the learning process. Duolingo's AI-driven platform uses machine learning algorithms to track user performance and adapt exercises to individual learning needs.

Example: Maria, a 28-year-old from Brazil, decided to learn Romanian in preparation for a job transfer to Bucharest. She chose Duolingo because of its user-friendly interface and the flexibility it offered. Initially, Maria struggled with Romanian's complex verb conjugations

and the pronunciation of certain sounds, such as the Romanian "ă" and "î". Duolingo's adaptive learning algorithms identified these challenges early on and began presenting her with additional exercises focused on these areas. The platform also used spaced repetition, a technique enhanced by AI, to ensure that Maria regularly revisited these problem areas, which helped reinforce her learning over time. Additionally, Duolingo's speech recognition feature provided Maria with immediate feedback on her pronunciation, allowing her to gradually improve her speaking skills without the need for a live tutor [16].

By the end of six months, Maria had progressed from a complete beginner to an intermediate level, capable of holding basic conversations in Romanian. This case highlights how Duolingo's AI can personalize the learning experience, addressing individual learner needs and improving language acquisition efficiency.

7.2 Custom AI Tutoring Solutions

Beyond mass-market platforms like Duolingo, some educational institutions and private tutors are developing custom AI tutoring solutions tailored specifically for learning Romanian. These solutions often incorporate machine learning algorithms to analyze student performance in real-time and adjust lessons accordingly.

Example: The University of Bucharest's Language Center developed an AI-driven tutoring platform called "RoboRomanian" for international students enrolled in their Romanian language courses. This platform was designed to complement traditional classroom instruction by providing students with personalized online tutoring sessions. RoboRomanian used AI to assess each student's language proficiency through initial diagnostic tests and ongoing assessments. Based on the results, the platform created individualized learning paths that focused on each student's weak points.

One student, John, a medical student from Nigeria, particularly benefited from RoboRomanian. He struggled with Romanian medical terminology and formal language, which were crucial for his studies. The AI system identified these weaknesses and tailored John's lessons to include more medical vocabulary exercises and formal conversation simulations. The platform also included AI-powered chatbots that simulated patient-doctor interactions in Romanian, providing John with a safe environment to practice and receive feedback on his language use in a professional context.

Over the course of a semester, John's proficiency in Romanian medical terminology improved significantly, as did his confidence in using the language in clinical settings. RoboRomanian's ability to provide targeted, context-specific practice exemplifies how custom AI tutoring solutions can enhance language learning, particularly in specialized fields [17].

7.3 AI-Enhanced Translation Tools in Professional Contexts

AI-powered translation tools like Google Translate and DeepL are not just useful for casual language learners; they also play a significant role in professional settings where Romanian is used.

Example: Sarah, an American journalist working for an international news outlet, was assigned to cover political events in Romania. Although she had basic knowledge of Romanian, she relied heavily on AI translation tools to assist her with research and communication. Sarah used DeepL to translate Romanian news articles and official documents into English. While working on a story, she encountered a complex Romanian idiom that didn't have a direct English equivalent. DeepL's AI algorithms, trained on large datasets, provided a contextual translation that retained the meaning of the idiom rather than translating it word-for-word. This allowed Sarah to accurately convey the nuances of the story to her English-speaking audience.

Moreover, Sarah used AI-powered language models like GPT to draft and refine her articles in Romanian before publishing. These tools helped her ensure that her writing was grammatically correct and stylistically appropriate for a Romanian audience. By the end of her assignment, Sarah's reliance on AI tools had not only enhanced her work quality but also improved her understanding of the Romanian language, as she gradually became less dependent on the tools for simpler tasks [18].

These examples demonstrate how AI is being integrated into both educational and professional contexts to support the learning and use of Romanian. The adaptability, personalization, and efficiency offered by AI-driven solutions are proving to be invaluable assets for learners at all levels.

These expanded case studies provide concrete examples of how AI is utilized in different aspects of learning and using Romanian, showcasing the technology's versatility and impact.

8. Conclusion

AI is playing an increasingly important role in the learning of Romanian as a foreign language. From personalized learning platforms to advanced translation tools, AI is making language learning more accessible, engaging, and effective. By leveraging adaptive learning algorithms, AI tailors the learning experience to meet the specific needs of individual learners, helping them overcome challenges unique to Romanian, such as complex grammatical structures and nuanced pronunciation. Tools like AI-driven speech recognition and translation software are also bridging gaps in communication, enabling learners to practice and improve their skills in real-time, and translating content with greater accuracy.

However, the integration of AI into Romanian language learning is not without its challenges. One of the primary obstacles is the limited availability of high-quality data for training AI models specific to Romanian. This scarcity of data can lead to less accurate predictions and feedback, especially when compared to more widely spoken languages like English or Spanish. Additionally, while AI has made significant strides in language processing, it still struggles with understanding and conveying cultural nuances, idiomatic expressions, and context, which are crucial for achieving true fluency in any language.

Moreover, the over-reliance on AI tools can pose a risk to the development of deep, intrinsic language skills. Learners may become too dependent on automated systems for translation and comprehension, potentially stunting their ability to think critically and independently in the target language. This raises important questions about how AI should be integrated into the learning process to complement, rather than replace, traditional methods of language instruction.

Despite these challenges, the future of AI in Romanian language learning holds immense promise. As AI technology continues to advance, we can expect improvements in the accuracy and cultural sensitivity of AI-driven tools. Emerging technologies such as virtual and augmented reality, when combined with AI, have the potential to create immersive environments where learners can practice Romanian in realistic, context-rich settings. Furthermore, the development of AI-driven tutors capable of real-time interaction and personalized feedback could revolutionize language education, offering a level of personalization and engagement that traditional methods cannot match.

In conclusion, AI is not just a tool but a transformative force in the realm of language learning. Its role in Romanian language acquisition is a testament to the broader possibilities AI offers in education. As we move forward, it will be essential to continue refining these technologies, ensuring that they are used effectively and ethically to enhance the learning experience while also addressing the limitations that currently exist. By doing so, we can unlock the full potential of AI to create more personalized, interactive, and immersive learning experiences, making the process of mastering Romanian—and other languages—more accessible and effective for learners around the world.

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EXPLORING LARGE LANGUAGE MODELS IN THE EDUCATION PROCESS WITH A VIEW TOWARDS TRANSFORMING PERSONALIZED LEARNING

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Abstract

Large Language Models (LLMs) represent a significant development in Educational Technology (EdTech), offering novel opportunities to create personalized, adaptive, and contextually rich learning experiences. By leveraging advanced Natural Language Processing (NLP) and Machine Learning (ML) techniques, LLMs can interpret learner queries, generate dynamic instructional content, provide targeted feedback, and scaffold understanding in real-time. This capacity aligns with long-standing pedagogical theories, including constructivism, scaffolding, and differentiated instruction, enabling tailored interventions that respond to each learner's background, proficiency, and goals. As such, LLMs have the potential to facilitate access to quality instruction, support lifelong learning, and enhance learner engagement. They also open the door to data-driven insights that can refine teaching strategies, support continuous curricular improvement, and inform policy decisions. At the same time, deploying LLMs in educational contexts raises important challenges. This paper contributes to the current state of knowledge on Artificial Intelligence (AI) in education by analyzing the theoretical foundations, technological architectures, practical applications, benefits, and limitations of LLMs. It emphasizes that while LLMs are powerful tools capable of transforming educational systems, their adoption must be governed by careful design choices, ethical vigilance, and a commitment to empowering human educators and learners rather than displacing them. Ultimately, LLMs should serve as mechanisms for genuine educational transformation, ensuring that as technology evolves, the teaching and learning processes remain deeply human-centered, inclusive, and forward-looking.

Keywords: Artificial Intelligence in Education, Large Language Models, Personalized Learning, Adaptive Learning Environments, Constructivist Theory, Scaffolding, Differentiated Instruction, Data-Driven Insights

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1. Introduction

In recent years, the educational landscape has undergone a profound shift, drove in large part by rapid advancements in AI and EdTech. Among the most significant developments in this domain are LLMs, such as GPT [1–3] and BERT [4–7], which have demonstrated remarkable capabilities in natural language understanding and generation. Their potential to facilitate adaptive, responsive, and contextual aware learning experiences indicates that these models could play an increasingly important role in shaping the future of education.

By processing vast quantities of textual data and generating contextually relevant, coherent responses, these models have the potential to revolutionize the way learners interact with educational content. Unlike traditional, static teaching materials, LLMs can adapt to individual student needs, thereby facilitating a more personalized, learner-centered educational experience. This capacity for customization is particularly significant in today's increasingly diverse classrooms, where students bring a wide range of backgrounds, learning styles, and proficiencies.

At their core, LLMs operate by leveraging complex neural architectures, such as transformer models [8–13], which excel in capturing intricate linguistic patterns and structures. Through training on extensive corpora, these models develop a nuanced understanding of language that enables them to handle tasks as varied as answering questions, summarizing texts, and providing targeted feedback on students' work. As they continue to evolve, LLMs stand to integrate seamlessly into digital learning platforms, serving as interactive tutors that guide students through their educational processes and cater to their unique learning trajectories.

A significant concern in contemporary pedagogy is the need to move beyond the traditional one-size-fits-all [14–17], instructional paradigm. The demand for personalized learning environments in which content, pacing, and complexity are tailored to individual learner profiles continues to grow as educators, policymakers, and researchers seek more effective and inclusive solutions. This capacity for personalized instruction draws upon several foundational educational theories that promote personalized learning approaches. Starting with constructivist principles that emphasize active knowledge construction to theories of scaffolding and differentiated instruction, research in pedagogy has long emphasized the importance of adjusting educational interventions to fit individual learner profiles [18–22]. The introduction of LLMs into learning environments aligns with these theories, providing practical opportunities to operationalize such concepts on a scale. Through iterative dialogues, data-driven assessment, and adaptive support, AI-based systems can encourage deeper engagement, critical thinking, and improved learning outcomes.

Conventional systems often struggle to meet these diverse needs, largely due to constraints on time, resources, and the capacity of human instructors to customize lessons for every student. The limitations of these systems emphasize the importance of exploring new approaches that can help all learners reach their full potential. By intertwining cutting-edge AI technologies with established pedagogical frameworks, LLMs represent a valuable step forward in the integration of education and technology. They offer opportunities to realize the long-standing aspirations of many educators by providing responsive, inclusive, and adaptive learning experiences that empower students to reach their full potential.

This article aims to examine the role that LLMs might have in the pursuit of truly personalized learning experiences. Specifically, it studies how these models can address existing gaps in individualized instruction, evaluate their efficacy in different educational contexts, and consider the ethical and practical limitations that accompany their use. By offering a critical perspective on LLM-driven personalization, this paper aims to inform researchers, educators, and policymakers of the opportunities and challenges that arise from integrating advanced AI tools into the educational process. Ultimately, this paper aims to contribute to the ongoing discussion within the scientific community regarding the future of teaching and learning, illustrating how LLMs might help reimagine and reshape educational systems to better serve every learner's unique needs.

The remaining of the paper is structured as follows: Section 2 depicts the theoretical framework related to the integration of LLMs into educational environments, Section 3 analyzes the LLMs' applications in the context of personalized learning, Section 4 studies the benefits of LLMs in education, while the challenges and limitations to the integration of LLMs into classrooms, online learning environments, and personalized tutoring systems are analyzed in Section 5, followed by the discussion and conclusions of the obtained results, which are depicted in Section 6.

2. Theoretical Framework

The integration of LLMs into educational environments rests upon a convergence of theoretical and technological key points. On the one hand, the computational evolution of LLMs [23–25], based on complex neural network architectures, massive pre-training corpora, and advanced tokenization strategies, provides the means to generate and process natural language at a level approaching human fluency. On the other hand, the pedagogical background that enables meaningful personalization in learning environments draws heavily from foundational and emergent educational theories [26,27]. These theories, which emphasize learner autonomy, knowledge construction, and incremental support, give conceptual shape to the use of LLMs as tools for differentiated instruction and adaptive learning. By examining both the computational and pedagogical architectures that inform the use of LLMs in the classroom, we can put forward a robust theoretical framework that

will guide future research, implementation, and evaluation of these rapidly evolving technologies (Figure 1).

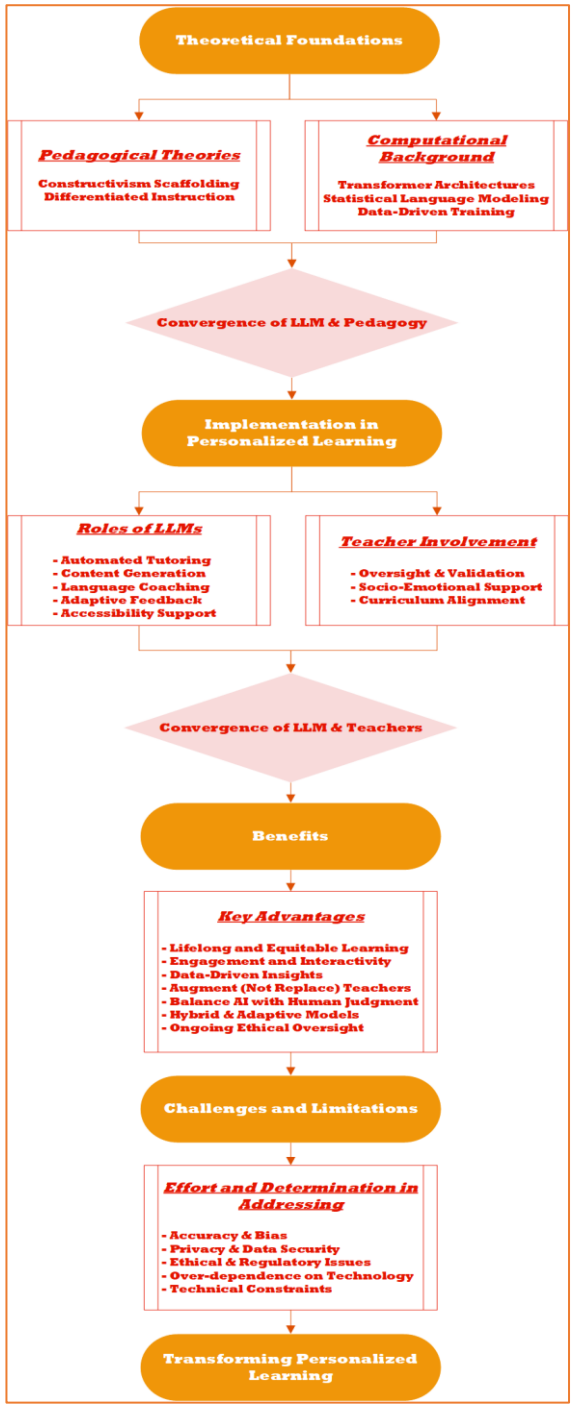

Figure 1. The proposed theoretical framework

LLMs are a category of advanced AI models designed to process, understand, and generate human-like text. Their core function is to produce coherent and contextually appropriate responses to a wide array of inputs, from simple questions to complex narrative prompts. The theoretical basis of LLMs in educational contexts consists of their capacity for linguistic generalization, namely these models learn probabilistic patterns of language use from massive, diverse textual datasets, and leverage these patterns to predict the next word or sequence of words given a prompt [23–25]. Understanding how LLMs perform this linguistic process, and how their internal representations align with human conceptual structures are very important aspects for deploying them successfully as educational tools.

The process by which LLMs understand and generate text is inherently statistical and data driven. Unlike rule-based NLP systems of the past, which relied on hand-crafted grammar and ontologies, modern LLMs build their linguistic abilities from statistical patterns gathered from large-scale text corpora. During training, models are exposed to billions of words drawn from books, academic papers, websites, and other sources, and they iteratively adjust their internal parameters to minimize the predictive error. In other words, the model learns to guess the next token (or sub-word unit) in a sequence of text. Over time and many training epochs, the LLM develops a complex, high-dimensional representation of language, encoding semantic and syntactic regularities in a set of parameters that can number in the hundreds of billions [23,25,28,29].

Once trained, the model's generation of new text involves selecting a sequence of tokens from probability distributions conditioned on previous tokens. When a user provides a prompt, the model's internal representations are used to identify the next most likely token, then the next, and so forth, until a coherent response is obtained. Adjustments such as temperature and top-k sampling can influence the creativity, variability, and specificity of the output. These sampling techniques allow for different instructional strategies. Therefore, a more conservative decoding might yield responses closely aligned with known facts, while more exploratory generation can prompt brainstorming or encourage critical thinking.

The majority of state-of-the-art LLMs are based on transformer architectures, which represent a paradigm shift from earlier recurrent neural networks (RNNs) [23,25,29] and convolutional neural networks (CNNs) [30,31] used in language tasks. Transformers use a mechanism called "self-attention" [8,23,25] to weigh the significance of different parts of the input sequence when making predictions. Rather than processing words strictly sequentially like RNNs or relying on fixed window sizes like CNNs, transformers consider all positions of a given input simultaneously [23,25,28,29]. This parallelism significantly improves training efficiency and allows the model to capture long-range dependencies in text.

In more concrete terms, the transformer architecture comprises multiple layers of self-attention modules and feed-forward neural networks. The self-attention mechanism

computes a set of attention weights that determine how much each input token should focus on every other token in the sequence [23,25,28,29]. This approach enables the model to understand complex grammatical constructs, reference previous elements across lengthy passages, and integrate contextual clues spread throughout the text. As a result, transformer-based LLMs excel at tasks like summarization, question answering, and content generation, all of which have direct relevance to educational personalization [9,10,13,17,25–27].

The notion of personalized learning is linked to a variety of well-established educational theories. Among these theories, constructivism [32–35], scaffolding [36–40], and differentiated instruction [41–44] have proven particularly significant. Each of these theoretical frameworks converges on a central idea, namely that learners construct knowledge more effectively when they engage in learning activities tailored to their cognitive readiness, prior knowledge, and personal interests. The introduction of LLMs into educational contexts must align with these frameworks to ensure that technology-mediated personalization is a genuine enhancement of the learning process, being much more than just a merely cosmetic adaptation.

Constructivist theory posits that knowledge is being constructed rather than transmitted [32–35]. Learners actively build mental models and internal representations of the world through experience and reflection, while learning occurs most effectively when it is situated in authentic contexts involving meaningful interactions with content. When LLMs are used for personalized learning, they can generate explanations and examples that reflect the learners' existing knowledge levels, cultural backgrounds, or interests. Consequently, a student interested in marine biology could receive science problems contextualized in ocean ecosystems, therefore creating a scaffolded pathway to new knowledge that feels more relevant and engaging. LLM-based systems ensure that the learner remains in a productive zone of learning and discovery by continually adapting to the learner's input and performance.

Closely related to constructivism is the concept of scaffolding, which emphasizes the importance of providing learners with the right level of support at the right time [36–40]. Scaffolding ensures that students tackle learning challenges slightly above their current skill level, therefore promoting growth without inducing frustration. The theoretical foundation of scaffolding defines the space between what learners can achieve independently and what they can achieve with expert guidance [40]. LLMs, by virtue of their capacity to generate immediate explanations, hints, and re-phrasings, can function as a dynamic scaffold. An example of this aspect consists in the fact that if a student struggles with a particular concept, the LLM can simplify the explanation, provide a hint that directs attention to an important piece of information, or pose a related but simpler question to build confidence. Over time, as the student's knowledge deepens, the LLM can reduce the level of guidance and encourage more independent problem-solving.

Differentiated instruction is an instructional approach that recognizes and accommodates the diverse needs, abilities, and interests of learners within a single classroom environment [41–44]. Traditionally, teachers differentiate instruction by altering the content, process, or explanations according to student readiness and learning profiles. Incorporating LLMs into this framework can streamline and enhance differentiation at scale. An example of this aspect is given by the fact that while one student might benefit from a more narrative-driven explanation, another student might prefer bullet-point summaries and factual presentations. With real-time adaptation, an LLM can provide multiple representations of the same concept. Moreover, the model can adjust the complexity of language, pace of delivery, and style of presentation based on the ongoing assessment of the student's comprehension. This aligns with the theory of differentiated instruction, ensuring that all learners have equitable opportunities to engage meaningfully with the content.

The deployment of LLMs within learning ecosystems embodies a broader intersection of AI and pedagogy. In this situation, the theoretical frameworks of constructivism, scaffolding, and differentiated instruction intersect with advancements in ML and NLP to create an environment ripe for adaptive learning. In these adaptive systems, the educational experience is neither static, nor uniform. Instead, it evolves dynamically, responding to the ongoing performance, interests, and goals of each learner.

Adaptive learning environments aim to optimize educational outcomes by delivering instruction and feedback that is adjusted to the learner's current state [45–49]. Historically, adaptive learning was achieved through teacher intuition, manual customization of materials, or rule-based software systems [46,47]. LLMs introduce a rapidly expanding capability, offering flexible, context-aware personalization that grows more fine-grained as the model encounters more learner interactions. Theoretical frameworks support this application as from a constructivist perspective, adaptive systems enable learners to follow unique learning trajectories, building knowledge structures that are personally meaningful and cognitively manageable [47,48]. At the same time, from the perspective of a scaffolding perspective, adaptive systems ensure that support is provided exactly at the point of need, and gradually faded as learners become more competent [48].

Beyond cognitive alignment, personalization also has motivational implications. Theoretically, when learners perceive instruction as relevant to their interests and goals, they exhibit greater engagement and persistence. Self-Determination Theory (SDT) in educational psychology highlights the importance of autonomy, competence, and relatedness in the development of intrinsic motivation [20, 50–53]. By using LLMs that adapt content and interact conversationally, learners are more likely to feel a sense of autonomy and ownership over their learning process. When the model customizes feedback and learning activities to align with learners' goals, therefore reinforcing their progress and acknowledging their accomplishments, it contributes to a sense of competence.

Additionally, the personalization of language and style potentially enhances relatedness as it can make the interaction feel more human-like and relational.

While LLMs offer remarkable opportunities for personalization, their integration must be guided by a theoretical understanding of the teacher's role. The teacher remains an extremely important actor who interprets assessment data, sets learning objectives, and promotes a supportive learning environment. The theoretical framework should emphasize that technology does not replace teachers but rather augments their capacity to provide individualized support. Teachers' expertise is indispensable for identifying the social, emotional, and cultural nuances, aspects that an LLM cannot fully grasp. Equally important is the teacher's ability to critically evaluate the responses generated by the model. By aligning LLM outputs with established curriculum goals and educational standards, the teacher ensures that these systems serve educational goals rather than distract from them.

The theoretical framework cannot be complete without acknowledging the ethical and equity dimensions at the intersection of AI and pedagogy. While personalization holds the promise of equal opportunities by offering support tailored to individual learners, it also risks perpetuating biases present in training data. Analyzing this aspect from a theoretical perspective, one can conclude that the educational community must apply critical frameworks such as critical pedagogy [54–56] and culturally responsive teaching [57–59] in order to ensure that the data used to train LLMs, as well as their outputs, reflect diversity and fairness. The theories underlying differentiation and scaffolding must be complemented by a commitment to inclusivity and social justice. Ensuring that LLMs support rather than hinder the educational advancement of marginalized communities is a fundamental ethical requirement.

Combining the computational complexity of LLMs with the nuanced insights of the educational theory, we arrive at a framework where AI-driven personalization becomes a natural extension of learner-centered pedagogy. The key theoretical pillars, namely constructivism, scaffolding, and differentiated instruction, guide the way in which LLMs should be implemented in order to support meaningful learning processes. At the same time, consideration of adaptive learning principles, motivational theories, and ethical implications situates this technological transformation within a broader educational ecosystem.

The theoretical framework for understanding the role of LLMs in transforming personalized learning is grounded in an interaction between advanced language modeling techniques and foundational educational theories. It acknowledges that LLMs bring unparalleled capacity for real-time, context-sensitive adaptation of instructional materials. By rooting these technological capabilities in constructivism, scaffolding, differentiated instruction, and related theoretical constructs, educators and researchers can ensure that LLM-driven

personalization serves not just as a tool for convenience, but as a promoter for genuine educational transformation.

In the following, we are focusing on analyzing the LLMs' applications in the context of personalized learning.

3. Applications of LLMs in Personalized Learning

The impactful potential of LLMs in educational contexts can be observed most clearly in their capacity to facilitate highly personalized learning experiences. In contrast with traditional forms of digital instruction such as static e-learning modules or one-size-fits-all tutoring systems that have been limited by their lack of adaptability, LLM-based systems can integrate nuanced understanding of language and context to deliver richer, more tailored educational support. As these models become more evolved in processing natural language, they can assume varied roles, such as personalized tutors, content creators, language coaches, adaptive feedback providers, and accessibility facilitators.

Automated tutoring systems (ATS) [60] have a longstanding history in the realm of EdTech, with early systems such as Carnegie Learning's Cognitive Tutor [61] and AutoTutor [62] demonstrating the feasibility of computer-based instruction that adapts to learners' needs. Nevertheless, previous generations of ATS often relied on fixed rules, predefined question-answer pairs, or limited dialogue trees. They struggled to engage students in more natural, free-flowing conversations, and lacked the ability to interpret nuanced student queries. LLMs, equipped with advanced natural language understanding, have begun to overcome these limitations, enabling truly dynamic and student-centered interactions.

One of the core advantages of integrating LLMs in automated tutoring systems is their ability to interpret and respond to a broad array of learner inputs. Traditional ITS (Intelligent Tutoring Systems) [60] often depended on a narrow domain model and limited sets of correct or incorrect student responses. By contrast, LLMs can parse open-ended questions or explanations from students and provide contextually relevant answers. Therefore, if a student studying algebraic functions asks, "Why do we factor equations before solving them?" a traditional ATS might only be equipped to output "Factoring makes it easier to solve." An LLM-based tutor can provide an in-depth analysis, explaining the underlying principles, exploring various factoring techniques, and even drawing analogies to help the student conceptualize the process.

This capability results from the extensive pre-training of LLMs on large-scale, domain-agnostic text corpora. As a result, the models can produce responses that are linguistically diverse and semantically rich. They can handle follow-up inquiries, adapt explanations to simpler language if students are struggling, or provide more technical details if a student demonstrates mastery. This agility supports a more learner-centered approach, where the

direction and depth of instruction can be guided by the student's curiosity and comprehension level, rather than being strictly dictated by a pre-coded curriculum script.

Moreover, LLM-based tutoring systems can integrate contextual cues from earlier parts of a conversation. If a student has previously expressed difficulty with a particular concept (e.g., understanding the difference between a linear and a quadratic function), the system can recall that struggle and build upon previous explanations. Over time, this creates a more personalized, apprenticeship-like model of learning, where the tutor "remembers" the student's history and tailors the ongoing instructional discourse accordingly.

Beyond conversational tutoring, one of the most powerful applications of LLMs in personalized learning environments consists of their ability to generate custom educational content. Content creation has traditionally been a laborious and time intensive task, requiring educators or content developers to produce vast arrays of materials like lesson plans, quizzes, summaries, case studies, and supplementary readings in order to cater to diverse student needs. By offloading some of these tasks to LLMs, educators can produce more efficiently a variety of materials attuned to their learners' skill levels, interests, and learning objectives.

LLMs can create or adapt lesson plans that align with specified learning outcomes, curricula, or standards. As an example, an educator might provide a prompt specifying a certain subject area (e.g., Databases), target grade level, learning objectives, and preferred teaching methodologies. The LLM can respond with a detailed lesson plan that includes suggested readings, activities, discussion questions, and assessment strategies. These generated outlines can then be reviewed, refined, and validated by human educators, drastically reducing the initial preparation time and enabling teachers to focus on delivery and adaptation.

In addition, LLMs can facilitate the generation of quizzes, problem sets, and comprehension checks that target specific student needs. As an example, if a group of students is struggling with a particular algebraic concept, an LLM can produce a set of incremental practice problems that gradually increase in difficulty, complete with hints and step-by-step solutions. Similarly, for more advanced learners or those who demonstrate mastery of a subject, the LLM can generate more challenging or enriched focused questions to push their thinking further.

Explanatory materials such as glossaries, summaries, and simplifications of complex texts are another valuable output of LLM-based content generation. When considering a student struggling to understand a dense academic paper or a challenging literary passage, the student or educator could prompt the LLM to produce a summary written at a more accessible reading level, ensuring that the key concepts are conveyed in simpler terms. The same mechanism can be used to produce multilingual content, enabling students from diverse linguistic backgrounds to access the material more easily and inclusively.

While the generative capacity of LLMs is substantial, it also raises important questions about quality assurance and pedagogical appropriateness. Educators need to ensure that the generated content is factually accurate, free from biases, and in alignment with established educational standards and curricula. Mitigation strategies might include embedding "expert-in-the-loop" workflows where human instructors review and approve generated materials, employing automated fact-checking tools, and using fine-tuning techniques to align LLM outputs with authoritative educational guidelines [63].

This iterative approach to content generation consisting of machine creation followed by human validation and refinement can gradually improve the trustworthiness and quality of educational materials. Moreover, as LLMs architectures evolve and incorporate retrieval augmentation [64,65], they can ground their answers and the generated materials in verified databases and knowledge repositories, further enhancing the reliability of their outputs. Language learning represents one of the most natural domains in which LLMs can excel due to their inherent linguistic capabilities. Traditional computer-assisted language learning systems often rely on static dictionaries or grammar exercises. LLMs, with their contextual understanding and generative fluency, have the potential to transform language instruction into an interactive, responsive, and highly personalized experience.

One core advantage of LLMs in language learning is their ability to provide immediate, granular feedback on learner outputs, whether spoken or written. As an example, when a student learning French writes a short paragraph, the LLM-based language tutor can instantly highlight grammatical errors, suggest more natural phrasing, or offer synonyms that better capture the intended meaning. This exceeds the capabilities of many grammar-checking tools by providing explanations grounded in context, not just isolated grammar rules mistakes.

In the case of speech-based language learning, LLMs integrated with speech recognition can listen to a learner's pronunciation and provide corrective feedback. While phonetic-level corrections may still require specialized models or pairing with speech-oriented systems, LLMs can offer guidance on word choice, sentence construction, and discourse-level coherence. By engaging in simulated conversations, language learners receive the kind of immersive, adaptive practice which was once limited to one-on-one tutoring with a human interlocutor.

Language learning is not just about mastering syntax and vocabulary. It also involves understanding cultural nuances, pragmatics, and social contexts. LLMs can be prompted with role-play scenarios in which the learner negotiates meaning, learns the appropriate registers of speech, or adapts communication style depending on the context. An example of this aspect consists in the fact that learners might interact with an LLM pretending to be a shopkeeper in a foreign market, a travel agent, or a friend discussing everyday life events.

Through these simulated interactions, learners can gain exposure to cultural references, idiomatic expressions, and conversational norms that static learning tools rarely provide.

Additionally, LLMs can explain the reasoning behind certain linguistic forms, enabling learners to develop a meta-linguistic awareness. By understanding why certain sentence constructions are preferred or how certain idioms originated, learners deepen their comprehension and become more autonomous language users. Over time, this continuous, on-demand feedback supports sustained engagement and skill acquisition.

Adaptive feedback is at the core of personalized learning [66,67]. While fixed learning modules provide the same hints and corrections to all learners regardless of their understanding, LLM-based systems can tailor feedback to each individual's cognitive profile, knowledge state, and emotional engagement. By doing so, these systems deliver incremental support that is neither too challenging nor too simplistic, therefore optimizing the area of proximal development and enhancing motivation and learning outcomes.

Adaptive feedback involves more than just correct or incorrect classifications. It requires systems to identify where a student stands in relation to the learning objectives and to guide them towards improvement. LLMs can monitor the types of errors students make, the complexity of the questions they ask, and the speed at which they are grasping new concepts. An example of this aspect is given by the fact that a student who continuously struggles with understanding the concept of photosynthesis in a biology course may require feedback that breaks down the steps more explicitly, includes analogies to everyday phenomena, or employs visual descriptions. Another student who quickly masters the core idea might be guided towards more advanced topics, such as exploring the electron transport chain or discussing the evolutionary significance of photosynthesis.

LLMs also allow for a more human-like conversational interface when delivering feedback. Instead of presenting static hints, the system can discuss the student's reasoning process, ask probing questions, and encourage reflection. By encouraging metacognition, where students think about their own thinking, LLMs can help learners identify their gaps in understanding and take an active role in addressing them.

Beyond purely cognitive adaptations, feedback can also be emotionally supportive or motivational. Research shows that positive affect and encouragement can improve learning engagement and retention [68]. LLMs, equipped with natural language understanding, can identify signs of frustration or confusion in a learner's responses and adjust the tone and content of the feedback accordingly. If a learner expresses discouragement, the model might respond with empathetic reassurance, reminding the student that effort is a normal part of the learning process and offering strategies for managing difficulty.

This kind of emotionally attuned feedback does not imply that LLMs possess genuine empathy as they rely on probabilistic inference of appropriate language patterns.

Nevertheless, well-tuned response strategies can create a more supportive and affirming environment, potentially increasing persistence and resilience. Over time, by analyzing which feedback styles and intensities correlate with improved performance, LLM-based tutors can become increasingly adept at providing optimal motivational scaffolding.

Personalized learning should be accessible to all students, including those who face a variety of challenges, whether cognitive, physical, linguistic, or socio-economic. LLMs offer several pathways to making educational materials and experiences more inclusive, from converting speech to text for learners with hearing impairments, to simplifying complex language for learners with reading difficulties, to generating multilingual content for linguistically diverse classrooms. Through these capabilities, LLMs help bridge educational gaps and ensure that no learner is left behind.

One extremely important application of LLMs is in supporting learners with sensory or motor disabilities. Consequently, learners with visual impairments may benefit from high-quality text-to-speech (TTS) services integrated with LLMs that can clarify terms, adjust reading levels, or provide definitions and explanations on demand. Conversely, learners who are deaf or hard of hearing can access speech-to-text services augmented by LLMs to produce transcripts that are both accurate and contextually enriched. The model can add clarifications or summarize key points of a spoken lecture to ensure learners grasp the material fully.

Cognitive disabilities, such as dyslexia or processing disorders, may require additional simplification of learning materials. LLMs can adapt reading passages to different levels of complexity, ensuring learners encounter content at a level that does not overwhelm them cognitively. By employing controlled language simplification and scaffolded explanations, LLM-based systems empower students to learn at a comfortable pace. This provides an individualized path toward comprehension, encouraging greater confidence and autonomy in learners who might otherwise struggle with standard curricula.

In increasingly diverse and globalized classrooms, language barriers often impede student engagement. Even well-designed curricula may be inaccessible to learners who lack proficiency in the language of instruction. LLMs can help break down these barriers by providing on-the-fly translations of instructional materials, quizzes, and teacher explanations into multiple languages. Unlike static translation tools, LLM-based translators can consider context, cultural nuances, and subject-specific terminology, producing more accurate and pedagogically meaningful translations.

Furthermore, LLMs can facilitate code-switching and multilingual dialogues in the learning process. A learner with limited proficiency in the primary language of instruction could engage in a bilingual conversation with the tutor system, gradually transitioning to greater use of the target language as their proficiency improves. This scaffolded approach encourages language development while maintaining cognitive engagement with the

subject matter, ultimately reducing the academic disadvantages faced by non-native speakers.

By extending personalization features to accommodate diverse needs and backgrounds, LLMs can help reduce educational inequities. Students who previously lacked access to specialized tutors, adaptive materials, or culturally responsive content might now receive tailored support. In underserved regions with limited educational resources, LLMs integrated into low-cost devices or offline-capable platforms can bring high-quality, adaptive instruction to communities that could not have previously afforded it.

It is important to take into consideration that merely introducing LLMs does not solve all systemic challenges. Structural inequities, digital divides [69], and insufficient infrastructural support can limit the reach of these technologies. Policymakers, educators, and developers must collaborate to ensure that the deployment of LLM-based educational solutions is accompanied by investments in teacher training, device distribution, reliable internet access, and community support. When implemented responsibly and comprehensively, LLMs can be an engine for educational inclusion rather than a source of further stratification.

In what follows, in order to further make an in-depth analysis regarding these aspects, Section 4 examines the benefits of LLMs in education.

4. Benefits of LLMs in Education

The introduction of LLMs into educational contexts has the potential to fundamentally reshape the way learners, educators, and institutions conceive of teaching and learning. The transition from traditional classroom-based instruction to more flexible, technology-enhanced paradigms has already begun, and LLMs promise to accelerate this shift by offering novel capabilities at a scale and level of personalization that was previously unattainable. By leveraging state-of-the-art NLP [70] and ML algorithms [71], LLMs can interpret, generate, and adapt textual content in a manner that closely mimics human-like understanding and communicative fluidity. This evolution has the potential to address longstanding challenges in education like accessibility, equity, personalization, learner engagement, and data-driven quality improvement.

Before the emergence of LLMs, many educational technologies such as intelligent tutoring systems, adaptive learning platforms, and virtual learning environments, relied on more constrained, rule-based methods that often fell short of delivering truly individualized learning experiences. Such traditional systems, while valuable, struggled to match the nuanced reasoning and contextual awareness that human educators provide. In contrast, LLMs can dynamically respond to complex queries, scaffold learners through challenging material, and adapt their approach based on ongoing learner interactions, performance data,

and continuously updated knowledge. As a result, LLMs offer a new frontier in education, where the boundaries of time, geography, and economic constraints are softened, if not erased, making high-quality learning support more accessible than ever.

The conventional model of classroom education [72], characterized by being predominantly instructor-led, resource-intensive, and location-bound, has historically created barriers for learners who lack proximity to well-resourced educational institutions or the financial means to afford private tutoring. By contrast, LLM-powered educational tools can operate virtually, delivering personalized assistance to an effectively extremely large number of learners simultaneously, regardless of their geographical location or economic background. This decoupling of education from traditional constraints holds the promise of democratizing learning opportunities worldwide.

In many regions, particularly in rural and economically disadvantaged areas, learners struggle to access qualified educators, up-to-date materials, and specialized instruction. Traditional solutions to these problems have included extensive teacher training programs, cross-border collaborations, and the distribution of textbooks or digital resources. Although valuable, these interventions are often insufficient in terms of reach, sustainability, and relevance. Textbooks rapidly become outdated, teacher-student ratios remain high in many regions, and digital infrastructures may be limited or unreliable.

LLMs can mitigate many of these obstacles by providing on-demand educational support. A student in a remote village with limited school infrastructure could, in principle, have access to the same learning assistant as a student in a major metropolitan area. Language barriers, a significant obstacle to global educational equity, can also be mitigated, as advanced LLMs increasingly support multilingual and cross-lingual functionalities. By rendering high-quality explanatory texts, examples, and exercises in a student's native language, LLMs ensure that world-class educational content is not restricted to the English language or to a handful of widely spoken languages, but it can rather be extended to minorities and endangered languages as well. This cross-lingual capability alone can have profound implications for preserving linguistic diversity and providing culturally relevant instruction.

Traditional large-scale educational interventions, such as Massive Open Online Courses (MOOCs) have suffered from high attrition rates and difficulties in providing individualized feedback [73]. With LLMs at the core of these platforms, personalization becomes possible at scale, rather than offering identical content to thousands of learners, an LLM can adapt its responses and support strategies based on each learner's progress, misconceptions, and interests. This personalized remediation ensures that even in massive cohorts, students do not get lost in the crowd. Therefore, an LLM-enhanced course could analyze the pattern of errors a student makes in computer science exercises and provide targeted hints, analogies,

or re-explanations tailored to that student's learning profile. By doing so at scale, these systems efficiently allocate cognitive support exactly where and when it is needed.

LLMs can be continuously updated and refined to reflect the latest research, pedagogical best practices, and real-time feedback from learners. This capacity for ongoing improvement stands in contrast to static educational materials that often become obsolete as curricula evolve, or as new knowledge emerges. Instead, LLMs can incorporate new datasets, revise their internal parameters, and learn from user interactions in order to enhance their accuracy and relevance. Such dynamic adaptability ensures that learners worldwide can benefit from the most up-to-date information without incurring large distribution or re-printing costs, a leap forward in both educational quality and cost-effectiveness. Consequently, scalability and cost-effectiveness represent opportunities to bring personalized, high-quality instruction within reach for billions of learners worldwide. LLMs are positioned to democratize educational access on an unprecedented scale by surpassing limitations of space, language, and infrastructure.

Beyond addressing issues of scale and cost, LLMs offer distinct pedagogical advantages that enhance student engagement and improve the overall learning experience. Engagement has long been recognized as a key determinant of academic success. Learners who interact more actively with content, who question their understanding, and who receive timely and context-sensitive support are more likely to retain knowledge, develop critical thinking skills, and sustain intrinsic motivation. Traditional instructional methods and static digital resources often fail to maintain this high level of engagement, leading to passive learning and lower mastery [14,26,32,51,72,74].

Conversational AI and LLM-driven virtual tutors can create a more dynamic and interactive environment, closely mirroring the role of a human tutor who listens, responds, and adapts to the learner's expressed needs. Through natural language interfaces, learners can engage in iterative dialogues, ask follow-up questions, request clarifications, challenge assertions, and explore alternative viewpoints. Such enriched interactivity can help break down the isolation often experienced in self-paced online courses, leading to more meaningful and enjoyable learning experiences.

In traditional learning scenarios, a student might rely on a textbook, video lecture, or instructor office hours to resolve confusion. Nonetheless, immediate and personalized feedback is often limited by time constraints and the availability of teaching staff. In LLM-driven environments, learners can ask questions at any time and receive immediate responses tailored to their current level of understanding.

LLMs can emulate a Socratic style of inquiry [75] by encouraging learners to reflect on their own reasoning processes. An example of this aspect consists in the fact that if a learner's question indicates a misunderstanding, the LLM can guide them through a series of related sub-questions, prompting the learner to rethink their assumptions or consider

alternative explanations. This dialogical approach, reminiscent of one-on-one human tutoring, can expand cognitive engagement by promoting a more active construction of knowledge rather than passive reception of facts.

Particularly in challenging subjects, learners benefit from scaffolded support that starts with simpler tasks and gradually progresses to more complex ones [36,40]. LLMs can play a role in providing customized scaffolds at the right moments. As an example, a language learner struggling with verb conjugation might first receive multiple-choice prompts and later be asked to produce verbs in context. As the learner's proficiency grows, the LLM can gradually remove these supports, encouraging independence.

Moreover, LLMs can also attend to the affective dimensions of learning. Although these models do not have emotions or genuine empathy, they can be programmed to respond in an encouraging, supportive tone, thereby reducing learner anxiety and building confidence. If a student expresses frustration or confusion, the LLM might rephrase explanations in simpler terms, offer analogies, or highlight the student's progress. This emotional and motivational support can help sustain engagement over time, especially for learners who lack strong external support networks.

A rich aspect of LLM-driven learning involves integrating text-based interactivity with other types of EdTech. While LLMs themselves are text-focused, they can facilitate richer learning experiences by guiding learners through virtual simulations, role-playing scenarios, or case-based learning. As an example, in the case of a virtual history course, an LLM might narrate a historical setting and then invite the learner to engage in a role-playing scenario, deciding strategies as a political leader, reflecting on trade policies, or negotiating alliances. The LLM can dynamically adapt the storyline based on the learner's choices, providing immediate feedback on the plausibility and consequences of their decisions.

This kind of interactive, narrative-driven learning can promote a deep level of engagement and help learners connect theoretical knowledge to real-world applications. The learner is no longer a passive recipient of historical facts, but an active participant in a complex scenario, testing ideas, grappling with uncertainties, and receiving timely, contextually relevant guidance from the LLM. Such immersive and conversational environments can increase motivation, reduce cognitive overload, and help learners internalize concepts more effectively.

Another dimension of engagement results from the LLM's potential to serve as a "peer-like" learning companion. Rather than interacting solely as a top-down tutor, the model can adapt its tone and complexity level to the learner's age, background, or personality. In the case of younger learners, an LLM might use simpler vocabulary, add an element of playful humor, or interject encouraging remarks to sustain interest, while for adult learners, the LLM might adopt a more formal and intellectually challenging style, engaging in debates or encouraging critical evaluation of ideas.

By creating a sense of rapport and personalization, LLMs can reduce the anxiety factor often associated with asking questions, allowing learners to explore content more freely. This collaborative and non-judgmental dynamic can spark curiosity, encourage experimentation, and ultimately lead to better learning outcomes.

In essence, LLMs hold the promise of creating a learning environment that is both more interactive and more responsive to individual learner needs. By putting forward engagement through dynamic dialogues, scaffolding, emotional support, immersive scenarios, and tailored communication styles, LLMs can transform the often passive, impersonal nature of digital education into a more human-centered and cognitively stimulating experience.

Beyond immediate instruction and engagement, one of the most impactful benefits of integrating LLMs into education consists in data-driven insights [14,28,33,69,76]. Education has long sought methods to obtain actionable information on how learners understand concepts, what challenges they face, and how instructional strategies can be refined for achieving maximal impact. Traditional assessments, while valuable, often provide only a snapshot of learner performance at specific points in time. They rarely capture the dynamic evolution of the learners' cognitive states, nor do they easily offer granular diagnostic insights that can be translated into targeted interventions.

LLM-embedded platforms can continually log interactions, parse learner queries, analyze patterns of mistakes, and track progress at a detail level that would be impossible to attain through conventional means. These systems can synthesize enormous amounts of structured and unstructured data, ranging from quiz results and open-ended questions to discussion forum posts and interaction logs, and convert them into meaningful analytics. Educators, instructional designers, and policymakers can leverage these analytics to understand where learners are struggling, which resources are most effective, and how pedagogical strategies can be improved with regard to both individual and systemic levels.

One of the most direct applications of LLM-driven analytics [77,78] is the provision of continuous formative assessment. Instead of waiting until the end of a term or a unit to identify learning gaps, LLMs can provide real-time indicators of learner understanding as they engage with study material. As an example, if a student consistently has difficulties with a particular concept in physics, the system can flag this issue early on and prompt the educator (or the system itself) to offer supplemental exercises, alternative explanations, or remedial modules.

Over time, as the system collects data from a large population of learners, it can identify common mistakes, challenging concepts, and frequently confusing instructional materials. Afterwards, instructional designers can refine these materials, revise lesson plans, or incorporate new teaching strategies that target these bottlenecks. In this way, data-driven insights enable a continuous improvement cycle where educational content and pedagogy evolve in response to empirical evidence of learner performance.

LLMs can also use learner data to individualize learning trajectories at scale. By analyzing each learner's past performance, preferred learning style, pace of progression, and areas of interest, the system can suggest an optimal path through a curriculum. As an example, if data suggests that a learner excels in conceptual reasoning, but struggles with rote memorization, the LLM might emphasize conceptual frameworks over raw facts, or present facts in more memorable contexts. Conversely, if a learner prefers a hands-on approach, the system might recommend interactive simulations, problem-based assignments, or case studies.

This fine-grained personalization extends beyond content delivery. An example of this aspect consists in the fact that the system could analyze patterns in the learner's engagement times by identifying when the learner has been most active or attentive, consequently scheduling challenging tasks during those peak periods. It might also track emotional cues (derived from language markers, response times, or patterns of difficulties in queries) to determine when to offer encouragement or when to switch tactics. In short, data-driven insights inform a dynamic adaptation process that treats each learner as a unique case, thereby maximizing learning efficiency and reducing failure rates.

A less obvious, but equally profound advantage of data-driven insights is the potential to explain and clarify the underlying cognitive processes of learning. By analyzing patterns of inquiries, sequences of mistakes and corrections, and the pathways learners take through educational content, LLM-based systems may offer clues about how learners think and learn. As an example, if certain types of hints systematically lead to better retention, instructional designers may infer that prompting learners towards self-explanation or analogical reasoning leads to a deeper understanding.

Moreover, LLMs can be configured to encourage metacognitive practices directly. Therefore, an LLM could periodically ask learners to reflect on their learning strategies by asking specific questions, such as "How did you arrive at that answer?" or "What is confusing about this concept?" and record the students' responses. By analyzing these reflections, educators can identify patterns of metacognitive skill and intervene to help learners become more self-aware and strategic in their learning. Over time, these insights can guide the development of pedagogical models that emphasize not just knowledge acquisition, but which also promote critical thinking, problem-solving, and self-regulation skills.

Beyond the classroom, aggregated and anonymized data-driven insights can guide institutional decision-making, curriculum development, and educational policy. School administrators can therefore identify which textbooks, or digital resources, produce the best outcomes across different demographics and contexts, allowing them to make more informed investments. Higher-level decision-makers, such as government agencies or non-profit educational organizations, can monitor performance trends across regions, schools,

or cohorts, identifying systemic challenges and targeting interventions where they are needed most.

This macro-level understanding, empowered by large-scale analytics derived from LLM interactions, can inform strategic decisions about teacher training programs, resource allocation, and curriculum standards. Over time, data-driven insights can help close achievement gaps, enhance teacher professional development, and ensure that educational systems evolve to meet the changing needs of society and the global economy.

While the promise of data-driven insights is significant, it is very important to acknowledge and address the ethical considerations that arise. The collection and analysis of learner data must be governed by stringent privacy protections, transparency about data usage, and mechanisms for learners and their guardians for controlling the scope and purpose of data collection. Biased or misinterpreted analytics can also perpetuate inequities rather than mitigate them. Therefore, if certain patterns of question-asking are correlated with a cultural or linguistic background, naively designed algorithms might label these learners as "low performing" without recognizing the cultural biases in the dataset or the LLM's training data.

Therefore, the successful integration of data-driven insights requires careful attention to fairness, accountability, transparency, and ethics. Stakeholders must work together to develop standards, regulations, and guidelines that ensure that learner data is used responsibly and that the resulting interventions serve all learners equitably.

The data-driven capabilities of LLMs represent a significant leap forward for evidence-based education. By continuously analyzing learners' interactions, performance, and cognitive processes, these systems can tailor instruction, inform educational strategies, and guide policy decisions with unprecedented precision. The era of data-rich, adaptive, and learner-centered education appears ready to fulfill its promise, provided that it is approached thoughtfully and responsibly.

The nature of learning is shifting as the world evolves at a rapid pace from the economic, technological, and social perspectives. In prior generations, education was often conceived as a discrete phase of life, namely one attended school or university to gain foundational skills and qualifications, after which formal learning tapered off in favor of professional work. Today, however, the concept of lifelong learning is gaining recognition as a critical component of personal development, career advancement, and civic engagement. In an era characterized by continual technological breakthroughs and shifting labor markets, individuals must continuously update their knowledge, learn new skills, and adapt to changing environments well beyond their initial schooling years.

LLMs have an extremely important role in enabling and enriching lifelong learning. Their scalability, personalization, and interactivity are not confined to a particular age group,

academic subject, or educational institution. Instead, these models can support learners of all ages and backgrounds, helping them acquire new competencies, revisit forgotten skills, and explore new domains of knowledge at their own pace. By making high-quality educational support available on-demand and facilitating self-directed, adaptive learning, LLMs can empower individuals to remain intellectually active, relevant, and engaged throughout their lives.

Modern workers face an unprecedented demand for upskilling and reskilling. Rapid technological innovations render some jobs obsolete while creating new professions that require entirely different skill sets. While professional development courses, workshops, and online programs exist, they often lack the real-time, context-aware support that LLMs can provide.

If one considers a marketing professional who needs to learn the basics of data analytics to remain competitive in the job market, they can interact with an LLM tutor that provides targeted instruction instead of enrolling in a lengthy course with fixed schedules and generic content. The LLM can explain key statistical concepts, help interpret datasets, and even simulate data analysis scenarios. As the learner gains confidence, the LLM can gradually introduce more complex concepts or suggest additional resources. This real-time, just-in-time learning model fits seamlessly into a busy professional's schedule, making it easier to integrate learning with everyday work tasks.

Similarly, entrepreneurs exploring new fields, retirees taking up a new hobby, or community members seeking civic education can all benefit from LLM-based lifelong learning platforms. By lowering the time and cost barriers to further education, these systems encourage people to remain intellectually stimulated and engaged, continually broadening their horizons.

Lifelong learners often have highly individualized learning goals that do not align precisely with standard curricula or traditional educational credentials. Some might seek to understand a new programming language, others might want to make an in-depth analysis into astronomy for personal interest, while others might want to improve their financial literacy to make informed decisions about investments.

LLMs can accommodate this diversity by tailoring learning pathways to each learner's aspirations. A user exploring astronomy purely out of curiosity may value comprehensible explanations, beautiful imagery, and fun facts. Another user who needs to learn programming for a job transition may require more rigorous, skill-based exercises, sample code snippets, and project-based learning. The LLM can adapt its instructional style, complexity, pacing, and tone to match these differing objectives, ensuring that each learner's time is used efficiently and enjoyably.

Lifelong learning is not merely about accessing information, it also involves cultivating self-regulatory skills, including setting goals, planning study sessions, monitoring progress, and evaluating outcomes. LLMs can help learners develop these metacognitive skills by prompting reflection, suggesting efficient study strategies, and recommending periodic self-assessments. Over time, learners become more adept at directing their own learning journey, confident in their abilities to find and use resources effectively.

An LLM could remind a learner to revisit challenging material after a certain interval, check their understanding through adaptive quizzes, or help them create a personalized study plan for a new skill they want to master. This guidance can help learners build habits that support continuous improvement, enabling them to become more independent and proactive learners.

Lifelong learning often occurs in informal settings through diverse activities like reading articles online, watching educational videos, participating in community workshops, or experimenting with hands-on projects [79]. LLMs have the potential to seamlessly unify informal and formal learning. While informal learning can be rich and diverse, it is often unstructured and difficult to track. By integrating LLM-based tutoring and analytics, learners can structure their informal exploration into a more coherent learning experience.

A learner who reads several articles on a new technology could ask the LLM to summarize the key points, highlight areas that need further exploration, and suggest a progression towards mastering the topic. If the learner decides to move into a more formal setting such as an accredited online course, the LLM could help prepare them by reviewing prerequisite knowledge, recommending materials, and providing practice problems aligned with the course's objectives. In this way, LLMs can act as a constant educational companion, supporting learners as they manage through self-directed exploration and more structured learning environments.

While LLMs excel at one-on-one interactions, lifelong learning also benefits from social contexts where individuals learn from peers, mentors, and communities of practice. LLMs can facilitate the formation and maintenance of learning communities by helping match learners with similar interests, suggesting relevant discussion forums, or providing scaffolds for collaborative projects. While not a direct replacement for human social interaction, an LLM can act as a connector and a moderator, curating content, encouraging constructive dialogue, and helping learners to put forward their thoughts in a community setting.

An LLM could moderate an online forum on an important topic, encouraging participants to share their experiences, highlight best practices, and question assumptions. By providing fact-checks, summarizing debates, or suggesting avenues for further exploration, the LLM helps maintain a high-quality, respectful discourse that benefits all participants. Such

communities can serve as catalysts for lifelong learning, stimulating curiosity, collective problem-solving, and the exchange of expertise.

Lifelong learners are an incredibly diverse population. They may come from different cultural backgrounds, speak different languages, and have varying levels of prior knowledge. LLMs can cater to this diversity by providing multilingual support, culturally sensitive explanations, and domain-specific expertise across a wide range of fields. Whether someone wants to learn about traditional arts in their heritage culture, gain knowledge of local environmental issues, or explore cutting-edge research in biotech, LLMs can tailor the experience to reflect the learner's cultural context, language preferences, and intellectual goals.

As global connectivity increases, so does the diversity of knowledge seekers. LLM-driven educational platforms can serve as global knowledge hubs, ensuring that learners around the world have equal opportunities to engage in lifelong learning. This democratization of knowledge empowers individuals, communities and societies, promoting more informed citizenries and facilitating cross-cultural exchange and innovation.

The benefits of LLMs in education extend far beyond simple efficiency gains or incremental improvements to traditional instruction. By harnessing the capabilities of these advanced models, education can become more scalable, inclusive, and cost-effective, ensuring that high-quality learning opportunities reach learners across the globe. The interactive and engaging nature of LLM-driven environments supports active participation, curiosity, and deeper comprehension, while the data-driven insights gleaned from learner interactions enable continuous refinement of teaching strategies and policies. Most importantly, LLMs play a very important role in promoting lifelong learning, enabling individuals to continuously adapt, grow, and contribute to an ever-changing world.

As these technologies mature, it will be necessary to address the ethical, regulatory, and pedagogical challenges they pose. Issues such as data privacy, algorithmic bias, and the need for transparent evaluation metrics must be resolved to fully realize the rapidly increasing potential of LLMs in education. With thoughtful design, rigorous oversight, and inclusive implementation strategies, LLMs can catalyze a new era in which personalized, data-driven, and lifelong learning becomes the universal norm, empowering learners everywhere to realize their full potential.

In order to make use of all these benefits, one should take into account the fact that the integration of LLMs into classrooms, online learning environments, and personalized tutoring systems poses numerous challenges and limitations that will be further analyzed in the following section.

5. Challenges and Limitations to the integration of LLMs into classrooms, online learning environments, and personalized tutoring systems

Ensuring the reliability and factual accuracy of LLM-generated content remains a significant issue. Models that have not been carefully fine-tuned or grounded in authoritative sources risk propagating misinformation, misunderstandings, or cultural biases. As learners increasingly rely on automated tutors or content generators, it becomes very important to validate the outputs through peer review, educator oversight, or integration with trusted knowledge bases.

An important challenge consists in measurement and evaluation. It is a difficult task to assess properly the effectiveness of LLM-based tutoring systems, adaptive feedback, or content generation at scale. Traditional metrics of educational achievement, such as standardized test scores, completion rates, or course grades, may not fully capture the nuanced improvements in learning processes that LLMs enable. Future studies must develop new assessment frameworks, leveraging learning analytics and learner modeling to track growth in understanding, critical thinking, problem-solving, and engagement over time.

Ethical considerations also come to the forefront. The adaptive personalization offered by LLMs depends on processing large amounts of learner data. Designers and policymakers must consider how to protect student privacy, ensure data security, and comply with regulatory frameworks such as the General Data Protection Regulation (GDPR) [80] in Europe or the Family Educational Rights and Privacy Act (FERPA) [81] in the United States. Additionally, the presence of cultural or gender biases in LLMs could inadvertently disadvantage some learners or perpetuate harmful stereotypes. Researchers and developers must commit to ongoing bias detection, mitigation, and the involvement of diverse stakeholders in model training and evaluation processes.

As the field matures, a promising direction is the integration of LLMs with other modalities and emerging technologies. Speech and vision models can be combined with LLMs to create multimodal learning environments that blend text, audio, images, and virtual reality simulations. It is very important to take into account that while LLMs can greatly enhance personalized learning, they are not substitutes for human teachers and mentors. The human element in education, namely motivating learners, addressing emotional needs, contextualizing knowledge, promoting creativity, and cultivating ethical reasoning remains irreplaceable. Teachers and LLM-based systems should collaborate symbiotically, with educators focusing on complex tasks that require deep expertise, empathy, and ethical judgment, while LLMs handle more routine and repetitive functions, adapt materials in real-time, and provide immediate support to students at scale.

The integration of LLMs into educational systems signifies a considerable shift in how personalized learning can be conceived and implemented. The potential of LLMs is both

broad and deep, ranging from automated tutoring systems that adapt to the individual learner's knowledge state, to the generation of customizable content aligned with student interests and abilities, to the provision of accessible, inclusive, and linguistically sensitive learning environments. Language models can serve as tireless tutors, resourceful content creators, language coaches for second-language learners, precise providers of adaptive feedback, and tools of accessibility and inclusion.

Attaining this potential requires careful stewardship. The field must address challenges related to accuracy, bias, privacy, and pedagogical integrity. Collaboration among researchers, educators, developers, policymakers, and among learners themselves will be of utmost importance to shaping the role of LLMs in education. Through iterative refinement, continuous evaluation, and human oversight, LLMs can become a powerful tool in the collective effort to deliver high-quality, equitable, and effective personalized learning experiences to students everywhere.

Ensuring that LLM-driven educational materials maintain high standards of truthfulness and cultural sensitivity is a very important task. Misinformation is not limited only to falsehoods, it can manifest subtly, such as through incomplete explanations, unwarranted assumptions, or failing to offer a comprehensive view of a topic. This subtlety is especially concerning in educational contexts, where learners may lack the foundational knowledge or critical thinking skills needed to question dubious statements. The ability of LLMs to generate confident-sounding responses can further exacerbate this issue. An LLM might produce a plausible but factually incorrect explanation of a scientific concept, which a learner might accept without skepticism. Over time, such inaccuracies can accumulate, potentially hindering a student's academic growth and distorting their conceptual frameworks.

The integration of LLMs into education often entails the accumulation, analysis, and storage of vast amounts of learner data. This data may include personal information, academic records, learning preferences, and even sensitive behavioral indicators. While the personalization afforded by LLMs is contingent on harnessing such data to personalize content and support, the large-scale collection and processing of information raise significant privacy and security concerns. The risks go beyond mere data leaks considering that they encompass the potential for misuse of personal data, unauthorized profiling of students, and threats to student autonomy and agency.

Data collection in educational contexts can bring both advantages and challenges. On one hand, fine-grained learner data empowers educators and AI systems to identify learning gaps, adapt instruction dynamically, and provide timely feedback. On the other hand, without strict safeguards, these data points can be exploited for purposes unrelated to education. Commercial interests might therefore seek to mine learner data for targeted advertising or other marketing-driven initiatives. Furthermore, if data is not being managed

properly, it could be used to infer sensitive characteristics about a learner, such as health conditions, political beliefs, or religious affiliations. This form of invasive profiling violates ethical principles, and it might also stigmatize or disadvantage learners.

Despite remarkable advancements, LLMs still face a variety of technical limitations [23,29,69,77,82] that can impede their effectiveness in educational applications. These models, while increasingly fluent and context-aware, are fundamentally pattern-matching systems that rely on statistical regularities within their training data rather than on true comprehension or reasoning. While state-of-the-art LLMs appear impressively knowledgeable, they do not possess genuine understanding of concepts, emotions, or the contextual nuances that humans are able to manage with relative ease. This gap between surface-level fluency and deep understanding can lead to several issues when LLMs are being applied in educational scenarios.

One of the most significant technical constraints is the difficulty LLMs have in handling domain-specific or context-sensitive queries. Considering the situation where a student might ask a question that relies on prior lessons, localized educational standards, or a particular cultural perspective, one might notice that while a well-trained LLM might recognize patterns from its training data, it may still struggle to reason about the implications of a question in a localized curriculum context or accurately interpret instructions that depend on a very specific educational environment. Similarly, if a student's inquiry involves multiple steps of logical reasoning like solving a complex mathematics problem or interpreting a literary passage with layered metaphors, the LLM might fail. Although some models have been augmented with reasoning chains and external tools [83–88], the innate limitations of their underlying architectures constrain their reliability and depth of comprehension.

Another technical challenge consists in the models' inability to access and continuously update their knowledge of the world. Once trained, LLMs are essentially static snapshots of linguistic patterns at a given point in time. They do not have an inherent mechanism for self-updating based on new information, nor do they have true "experience" or "memory" in the human sense. Although techniques like fine-tuning [25,76,83,85], retrieval-augmented generation [64,65], and connecting models to external knowledge databases can partially alleviate this limitation, these solutions are often insufficient. Over time, a model's output can become outdated or misaligned with the current consensus in rapidly evolving disciplines such as computer science, medicine, or environmental studies.

A related complexity is the challenge of modeling pedagogical strategies effectively. Skilled human educators adjust their explanations, tone, and complexity based on a student's responses, prior knowledge, and emotional state. Achieving this level of adaptive instruction requires not just language understanding but also a model of the learner's state of knowledge and motivation. Current LLMs lack the ability to genuinely "model the

learner" [23,29,77,82] with the same granularity and context sensitivity that a human teacher employs. While ongoing research explores techniques for user modeling and context tracking, such as maintaining long-term memory or integrating student analytics into the model's decision-making process, these methods remain nascent and imperfect.

Moreover, computational costs and infrastructural requirements also pose constraints. Large-scale models demand substantial computational resources for training and inference [23,77,82]. In many educational settings, particularly those in resource-constrained regions, it may be impractical or economically burdensome to deploy state-of-the-art LLMs. The need for specialized hardware, stable high-bandwidth internet connections, and ongoing maintenance creates inequalities between well-funded institutions and those with limited budgets. Without more efficient models, compression techniques [89,90], or on-device deployment strategies, these technical limitations can restrict the democratization of LLM-driven education.

Addressing these technical barriers requires ongoing interdisciplinary research. Advances in ML architectures might result in models that are better at reasoning, contextual interpretation, or incremental learning. Integrating knowledge graphs, symbolic reasoning modules, or explicit pedagogical frameworks could help unify language fluency and conceptual understanding. Improvements in algorithmic efficiency will also be needed to ensure that LLM-driven tools are accessible across diverse educational environments. While these technical challenges are important, they also represent opportunities for innovation. By collaborating with educators, cognitive scientists, linguists, and policy experts, developers can strive to create LLMs that genuinely support learning outcomes rather than merely simulating understanding.

As educational systems increasingly integrate LLMs and other advanced technologies into their instructional methods, concerns arise about the risks of over-dependence. While technology offers unprecedented opportunities for personalized learning, global reach, and resource sharing, it also threatens to reshape the educational landscape in ways that may not always be beneficial. One major risk is that learners, educators, and institutions become overly reliant on automated tools, potentially diminishing the human elements of teaching and learning, such as empathy, creativity, and interpersonal feedback that are very important to proper education.

Over-dependence on LLMs may create a passive learning experience, where students come to expect instant answers rather than developing their critical thinking and problem-solving skills. If a student can turn to an AI tutor at any moment for a quick solution, they might miss opportunities to grapple with challenging material, engage in deeper inquiry, or learn from trial and error. In effect, the convenience of automated assistance can work against the cognitive struggle that is often essential for robust learning and mastery of complex concepts. This tension mirrors broader debates in education about the balance between

"productive struggle" [91] and guided instruction [92] but is exacerbated by the ease and immediacy of LLM-provided answers.

Over-reliance on LLMs can also reduce the incentive for institutions to invest in professional development and skilled human educators. There is a risk of seeing AI tutors as a cost-effective replacement for trained teachers, especially in environments where educational budgets are tight. While LLMs might handle some responsibilities, they cannot replicate the nuanced judgment, adaptability, and emotional intelligence that define professional educators. The danger is that education providers might come to view LLMs as a panacea, neglecting the professional growth of human teachers and ultimately impoverishing the educational experience. A successful educational system must balance the use of technology with a robust community of educators who guide, mentor, and inspire learners.

Moreover, heavy dependence on technology can make educational systems vulnerable to disruption. Technical failures, whether due to software bugs, cyberattacks, or infrastructural breakdowns, can halt learning processes, erode trust in digital systems, and leave learners stranded [93,94]. Without alternative modes of instruction or backup plans, educators and learners may find themselves unable to continue meaningful engagement with academic material. This fragility stands in contrast to more traditional educational systems, where a teacher and chalkboard require little more than a physical space and minimal resources.

In order to address this challenge, educational policies should encourage a balanced integration of LLMs. Hybrid models, where human teachers leverage LLMs as supplementary tools rather than as replacements, can preserve the benefits of personalization and scalability while maintaining human oversight and contextual judgment. Investments in teacher training can help educators understand how to integrate LLM-driven tools effectively, ensuring that they complement rather than supplant existing educational practices. Strategies to ensure equitable access, such as low-bandwidth solutions, offline versions of LLM-driven resources, or public infrastructure investments, will help mitigate the digital divide. Ultimately, a sustainable approach to LLM integration in education recognizes that technology is a means to enhance, rather than replace, the complex and deeply human endeavor of teaching and learning.

The challenges and limitations of LLMs in education are neither trivial nor entirely solvable with current technologies. They represent a dynamic, evolving landscape that reflects the complexity of learning itself. By recognizing these challenges, investing in remedies, and maintaining an unwavering commitment to the principles that underpin quality education, we can help ensure that LLMs become a force for good-enhancing personalized learning, expanding access, and ultimately contributing to a more informed, capable, and equitable global society.

The following section presents a discussion and the most important conclusions of our study regarding LLMs in the education process with a view towards transforming personalized learning.

6. Discussion and Conclusions

The integration of LLMs into educational systems marks a significant change in how teaching, learning, and assessment can be conceived and delivered. This article has analyzed the LLMs' remarkable potential for personalized education, moving beyond the static one-size-fits-all approaches to the more adaptive and context-sensitive instruction. Drawing on established educational theories like constructivism, scaffolding, differentiated instruction, and principles of lifelong learning, LLMs present a viable means of operationalizing learner-centered paradigms at scale. They can help bridge traditional resource gaps by providing accessible, on-demand tutoring and content generation that are finely tuned to individual needs, interests, and cultural contexts.

The benefits are clear, covering enhanced learner engagement through dialogue and interactive instruction, rich adaptive feedback loops facilitated by continuous assessment, and improved institutional decision-making through data-driven insights. By tailoring instruction to the nuanced demands of each learner's cognitive profile, LLMs have the potential to stimulate critical thinking, metacognition, and sustained motivation. They also offer pathways to support students with disabilities, learners of various linguistic backgrounds, and individuals pursuing non-traditional or lifelong learning trajectories, as a result broadening the reach and inclusiveness of quality education.

Nonetheless, this article also emphasizes that in order to attain this potential one has to grapple with very important challenges. Analyzing the issues from the perspective of an ethical standpoint, addressing algorithmic biases, ensuring factual accuracy, and cultivating culturally responsive pedagogies are non-negotiable tasks. Privacy and data security issues must be proactively managed, with transparent communication, regulatory compliance, and stringent data governance frameworks to maintain public trust and learner autonomy. Technical limitations such as the difficulty of handling complex reasoning tasks, integrating multimodal inputs, and maintaining up-to-date domain knowledge signal that LLMs are still evolving tools, not perfect substitutes for human expertise.

An extremely important aspect is the fact that the role of educators remains irreplaceable. While LLMs can reduce cognitive load, handle repetitive tasks, and personalize the learning experience, educators are the ones who provide empathy, ethical judgment, cultural sensitivity, and pedagogical creativity that machines and algorithms cannot replicate. The path forward involves positioning LLMs as complementary helpers rather than replacements. Hybrid models where educators organize the learning processes and leverage

LLMs for reinforcement, enrichment, and individualized support ensure that the human element remains central. This synergy empowers teachers to focus on higher-order tasks, guiding learners through complex intellectual challenges, facilitating critical discussions, and nurturing social-emotional growth.

Future work should explore strategies for integrating LLMs with other emerging technologies such as speech recognition, augmented reality, or advanced analytics to create encompassing, multimodal learning ecosystems. Longitudinal studies are needed to assess the long-term effects on learner outcomes, engagement, and equity. Moreover, ongoing collaboration among researchers, policymakers, practitioners, technologists, and learners themselves is necessary for establishing robust ethical guidelines, technological standards, and professional development protocols that can evolve with the field.

In conclusion, the discussion points to a future where LLMs serve as dynamic educational partners, amplifying human teaching rather than diminishing it. By balancing innovation with responsibility, inclusivity, and a shared vision of what quality education entails, the field can harness LLMs as an impactful force. Such a future promises more personalized, adaptive, and accessible learning experiences along with the reaffirmation of the core human values that define the educational process.

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THE ROLE OF MARKETING STRATEGY IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE

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Abstract

Artificial intelligence (AI) has emerged as a powerful tool for organizations in a variety of ways, automating processes to cut costs, analyzing data to provide financial insights, and more. But, according to McKinsey, marketing is where AI's impact will be greatest, automating tasks, but more importantly, analyzing data to provide insights to create more effective marketing strategies. At the same time, the use of artificial intelligence comes with certain risks, so companies need to strike the right balance between human marketing efforts and using artificial intelligence to enhance their efforts.

Keywords: artificial intelligence, marketing, profitability, ethics, transparency

JEL Classification: D8, D69, M31, O33

1. Introduction – AI potential in marketing

It is important to take a strategic approach to how companies and agencies can integrate this technology into their marketing activities in order to reap the benefits. Artificial Intelligence (AI) has found applications in different contexts in today's business landscape and is seen as a given for the success of today's and tomorrow's businesses. Experts and researchers see AI as the future of our society, and its adoption in marketing has gained ground, especially due to the ease with which content can be created

AI is changing the marketing industry by creating new opportunities [15] by changing the way companies communicate with their customers, i.e.:

- ✓ *data analytics* - AI enables marketers to monitor customer data and uncover hidden patterns and trends. This enables informed decisions by gaining a deeper understanding of customer behavior and preferences;

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- ✓ *content generation* - AI can generate personalized content, from product descriptions to social media posts, at scale. This frees marketers to focus on creative strategy and ensures content resonates with specific audience segments;
- ✓ *personalization* - AI analyzes individual customer data and behavior to enable hyper-personalized marketing experiences. Through dynamic content recommendations, personalized email campaigns and personalized product suggestions; AI-driven personalization drives deeper customer engagement and loyalty, boosting conversion rates and customer satisfaction;
- ✓ *audience segmentation and targeting* - AI algorithms can segment audiences, identify the most important customers, and activate targeted marketing campaigns. This maximizes campaign effectiveness and ensures resources are directed to the most responsive audiences;
- ✓ *programmatic advertising* - AI automates the process of buying and selling ad space, optimizing bid amounts in real time for maximum reach and profitability. This helps marketers save valuable time while delivering impactful ad campaigns;
- ✓ *search engine optimization (SEO)* - AI can analyze search trends and user behavior to inform SEO strategies. This helps marketers identify relevant keywords, optimize content for search engines and improve their organic search rankings.

2. AI in marketing

Artificial Intelligence (AI) is the technology with a tremendous capacity to transform the field of marketing in the years to come [12], being able to even surpass the impact made by technologies such as the Internet of Things, Big Data and blockchain.

Source: https://www.transilvaniabusiness.ro

In today's economic context, [9] marketing activities are characterized by complexity, and for most marketing managers, identifying the specific contexts where AI can be applied becomes necessary. The role of marketing strategy in the context of AI has changed, migrating from a role focused on efficiency and productivity to being more about predicting the next wave and preparing the company to seize opportunities.

A categorization of marketing activities is necessary in order to determine the context in which they are carried out and how they can be carried out successfully; thus, they can be categorized based on their characteristics and dynamics [12].

The simple category includes all marketing activities that already have a best-practice, a rule of thumb, and this can include classic offline campaigns (TV, outdoor, print, etc.), search engine optimization (SEO) or email marketing campaigns. The complex category includes all activities that can be solved by multiple tactics, where expertise is required, and here I am referring to market analysis, data interpretation and strategy development. Complicated are activities where there is a lot of ambiguity and the relationship between cause and effect is unknown. This category includes activities such as social media marketing, content creation, entering new markets and targeting new consumer segments.

Starting from this categorization of marketing activities, it is necessary to understand the types of AI technologies available (Table 1). Due to excessive media coverage, a misperception has been created that AI is all about generativity where you can easily make content and automate certain repetitive tasks. The potential of AI [6] is much broader and can be briefly classified into three broad categories of abilities: mechanical that can be used for standardization, cognitive for personalization of the created content and emotional for automatic relating. Tabel 1. Potențialul IA în funcție de activitatea de marketing

Marketing activity	**Platform**
data collection	ParseHub, Octoparse or import.io
market analysis	Brandwatch, Hootsuite Insights or Sprout Social
understanding consumer bahavior	Clarifai or Amazon Rekognition
product reporting	Affectiva, IBM Watson Customer, Experience Analytics Realeyes, Emotics, Clarabridge, Neuro-Insight
product customization	Hubspot, Marketo and Pardot
price customization	Zilliant, Vendavo, Dynamic Yield
setting prices dynamically	Omnia and Vendavo Price Optimization Aplications
placement and distribution	Sales Force Einstein, Adobe Sensai, Dynamic Yield, Oracle CX Unity, SAS Customer Intelligence

promotion of products and services	Chatfuel, Manychat and chatbot.com
personalizing messages	Blueshift, Persado and Emarsys
more interactive communication	Affectiva, IBM Watson Tone Analyzer, Receptiviti, Emotion AI de la Empath

Source: https://www.transilvaniabusiness.ro

- ✓ The role of artificial intelligence in marketing is growing exponentially. The revenue generated by AI in marketing has been estimated at more than $27 billion by 2023, and this figure is expected to grow to more than $107 billion by 2028. The top 28% of all businesses are already actively using AI marketing tools.
- ✓ its biggest impact comes from its ability to quickly analyze large amounts of data to provide insights about customers [2]; it can find out what customers like, where they go online, what buying patterns they have and what types of messages they respond to;
- ✓ can automatically create targeted and personalized ads on websites a customer visits;
- ✓ can analyze data by customer segments to determine the types of messages each segment responds to and which channels are most effective at reaching them; this allows marketers to create targeted marketing campaigns for each customer segment;
- ✓ chatbots and AI-powered virtual assistants on a company's website can be used to improve the customer experience on the website by answering questions and making personalized recommendations based on customer data;
- ✓ can help accomplish simple tasks; a new business can even use AI to create unique business names; for SEO, AI can help find keywords and perform SERP analysis.
- ✓ regarding the overall performance of your website, can assist with a website audit so that problems can be identified and steps taken to optimize the site;
- ✓ can automate social media posts and email campaigns and contribute to content can even create content; a better use of AI is to generate relevant content topics and create drafts of articles or posts that the editor can use as a basis;marketing strategies;
- ✓ One interesting use of artificial intelligence is in retail stores. *For example, home improvement store Lowe's has created an AI-powered app that customers can use in-store. It gives customers personalized product recommendations and information as they shop.*

It also tracks inventory in real time, which gives retailers insight into buying trends at any given moment. So they can focus their marketing efforts on on-trend products.

Source: https://www.ranktracker.com/

The use of artificial intelligence in marketing has a multitude of benefits, such as:

- ✓ one of which is improving efficiency and reducing costs; by automating tasks, marketing costs can be reduced by approximately 10% to 20%;
- ✓ saves time as AI can perform tasks quickly, allowing marketing efforts to reach target audiences faster;
- ✓ artificial intelligence can significantly improve the customer experience and increase engagement due to its ability to provide personalization on and off your website. Personalization then creates a connection between the customer and the brand, which, of course, increases the likelihood that they will make purchases;
- ✓ artificial intelligence also increases a company's ability to find qualified leads;
- ✓ the greatest benefits come from its ability to enable data-driven [2] decision making for marketing strategies, provide real-time insights and perform predictive analytics. By collecting huge amounts of customer information in real time and predicting customer behavior, marketing strategy will be continuously optimized without the need for a human to conduct hours of research. [10]

The adoption of artificial intelligence (AI) is having a positive impact on organizations, with six out of ten (60%) marketing executives overseas claiming to have used this technology in their activities over the past year, according to the results of a survey, cited by Agerpres. Thus, according to data analyzed by Deloitte in the latest edition of the Chief Marketing Officer (CMO) Survey [13] conducted by Duke University, with the use of AI, sales productivity improved by 6% and customer satisfaction by 7%, while indirect marketing costs decreased by 7% [14], thus:

- ✓ content personalization (53%) and content creation (49%) are the main areas where artificial intelligence is used in marketing activities;
- ✓ improving return on digital marketing investments by optimizing content and timing of activities (37%);
- ✓ programmatic advertising and buying ad space (35%);
- ✓ in the content creation segment, blogs (65%), website content (62%) and social networks (55%) are the main areas where organizations are using AI-based tools;
- ✓ nearly a quarter of marketers (24%) surveyed believe their organizations are making integrated digital investments, compared to just 14% last year (2022);
- ✓ Deloitte's report highlights a slight increase, up 2% from 2022, in spending on mobile marketing actions to 16% of the marketing budget, which will surpass the pandemic peak of 23% in five years, reaching an estimated 27%;
- ✓ marketing executives continue to report that mobile marketing makes a poor contribution to company performance (2.9 on a scale of 1 to 7), due to the difficulty of tracking the consumer journey across all digital interaction points (40%), the difficulty of linking mobile activities to overall marketing strategy (38%) and insufficient expertise of teams in this area (37%);
- ✓ spending on social media accounts for 16% of the marketing budget, and the study estimates that it will remain constant over the next 12 months, increasing by just 3%. However, over the next five years, it will surpass its pandemic peak of 23% to 24%;
- ✓ in terms of the skills of future marketers, the top priority identified by respondents is the ability to quickly reassess their approach as new priorities emerge, followed by creativity and the ability to innovate and navigate in an uncertain context.

The latest edition of the CMO Survey is the result of responses from more than 300 marketing executives across 15 industries in the US.

3. Integrating AI into marketing activities at tactical level

According to McKinsey the biggest financial benefits of AI have been seen in marketing and sales, product and service development, strategy and finance. Profitability is the main reason why companies have started to integrate AI into their marketing activities.
In the advertising industry, agencies have been quick to embrace AI, integrating it into their operations and the services they provide to clients. Some ad agencies have acquired technology companies and launched additional services. For example, WPP, the world's largest advertising agency, acquired London-based technology company Satalia and began

using AI to attract new clients and create campaigns such as Nike's 50th anniversary campaign.

Mark Read, CEO of WPP, sees AI as a creative tool rather than a replacement for their global workforce of 10,000, enabling true creativity to emerge. Publicis, on the other hand, has focused on data science and launched Publicis Sapient Data & AI capabilities to develop innovative solutions across industries using generative AI, natural language processing, computer vision and autonomous systems. Omnicom, in partnership with Microsoft, launched Omni Assist, a virtual assistant designed to support advertising agency employees with various tasks throughout the advertising process.

Corporations are also integrating AI into their marketing processes. Procter & Gamble has formed a multi-year partnership with Microsoft to transform its digital manufacturing platform to speed product delivery, improve customer satisfaction, increase productivity, and reduce costs.

Retailers have already integrated AI into their customer experience, both in-store and online, making it easier to find products, place orders and pick up parcels. H&M ensures that their most popular products are always in stock, while Sephora helps customers find the perfect lipstick shade through AI. Sephora has developed Color IQ which scans ladies' faces to give them personalized recommendations for foundation and concealer shades, while Lip IQ helps find the perfect lipstick shade.

Instead, Walmart plans to use robots to patrol aisles and scan shelves. The robots help identify missing products, replenishment needs and price tag changes, allowing employees to focus more on interacting with customers and stocking shelves.

4. Challenges

Everything has its drawbacks and risks [11], and the use of artificial intelligence in marketing is no exception. Data privacy and security concerns are one of the main risks associated with the use of artificial intelligence. AI-powered marketing systems require large amounts of data to operate, and storing and processing such large amounts of sensitive customer information increases the risk of data breaches.

Another risk comes from flaws that may be present in artificial intelligence algorithms. AI algorithms can inherit biases from the data on which they are trained, which can lead to unintentional discrimination in marketing campaigns. They can also inadvertently create customer profiles based on demographics and behavior, which can lead to targeted advertising that excludes or marginalizes certain groups of people.

Additionally, over-reliance on AI-driven personalization could lead to invasive and persistent targeting. When customers feel that their privacy is being invaded, this can lead to negative brand perceptions and decreased trust. This emphasizes the need for human intervention - only a human has empathy and sensitivity to the feelings of others.

Finally, using artificial intelligence to create content for marketing comes with potential problems. When it comes to content, empathy and human perspectives are essential for it to connect with readers. A company that uses AI-generated content thus risks risking its connection with its audience.

- ✓ *data quality and availability* - AI algorithms rely on large volumes of high-quality data to provide accurate insights. Marketers can face challenges in ensuring data quality, managing large volumes of data, incomplete or inaccurate data, and dealing with privacy issues;
- ✓ *interpreting incomplete data* - data collection for marketing often brings incomplete information such as social media posts, customer reviews and images. Interpreting these correctly requires advanced natural language processing (NLP) and image recognition skills, which can be difficult;
- ✓ *ethics and privacy issues* [1] - The use of AI in marketing raises ethical issues including privacy, transparency and fairness. Marketers need to navigate regulations, comply with data protection laws, and address concerns about fairness or discrimination in AI algorithms;
- ✓ *marketer - AI collaboration* - getting the right balance between human creativity, intuition and AI-guided analytics is essential. Marketers need to collaborate effectively with AI systems, using AI as a tool to support decision making rather than replacing human expertise;
- ✓ *algorithmic transparency* - AI algorithms can be complex, making it difficult to understand how specific recommendations or predictions are generated. Making AI algorithms transparent is important to build trust and explain marketing strategies;
- ✓ *continuous learning and adaptation* - AI models require continuous learning and adaptation to remain effective as the marketing context evolves. Regular updates and re-training of AI systems are required to identify changes in consumer behavior and market dynamics;
- ✓ *measuring profitability* - assessing the financial benefits of AI-based marketing initiatives can be complex. Accurately measuring the impact of AI on metrics such as customer acquisition, retention or revenue generated requires clear benchmarks, accurate tracking and precise attribution.

One possible solution to these risks could be to ensure ethical practices in AI, so first and foremost, companies need to implement robust data security measures to protect customer information from breaches.

It is also necessary to regularly audit artificial intelligence algorithms [5] for bias and take corrective action to ensure fair and ethical marketing practices. Finally, they must comply with data protection laws and regulations governing the use of personal data.

Companies need to strike a balance between AI-based marketing knowledge and human expertise. While AI can provide valuable data-driven guidance, it cannot replace the intuitive insight and creative vision that humans bring. Human expertise enables a deeper understanding of customer emotions, cultural nuances and context, allowing marketers to create narratives that resonate with their audience. In other words, artificial intelligence should enhance human marketing efforts, not replace them

To address these challenges, long-term strategic thinking, investment in resources, collaboration between marketers and IT specialists, and a commitment to ethical practices and transparency are essential. In conclusion, small businesses are likely to face additional constraints due to resource limitations, artificial intelligence and all of the above platforms are not cheap and to be able to integrate them all will require considerable investment.

The first step in using artificial intelligence for marketing is to identify and select data sources that are relevant to specific marketing objectives. Data must be accurate, reliable and representative of the target audience to avoid bias. By carefully analyzing data sources, marketers can ensure that AI algorithms are getting the right information, which will lead to more accurate predictions and insights.

In addition, before feeding data into artificial intelligence algorithms, thorough data cleaning and validation are essential to eliminate errors. This can improve the effectiveness of AI-based analysis, leading to more accurate results.

Lastly, while AI can analyze historical data to identify patterns and trends, it is essential to consider market dynamics and external factors that could impact the accuracy of predictions. Market trends, competitor activities and the economy in general are variables that can influence consumer behavior. Again, people are invaluable in integrating these variables with data.

To be accurate, artificial intelligence models need to be trained with regularly updated data [8] in addition, it is essential to monitor the performance of artificial intelligence tools and adjust algorithms regularly. As market conditions, consumer behavior and even business goals evolve, it is important to update AI algorithms to ensure their effectiveness.

Artificial intelligence also continues to evolve rapidly, so it's important to keep up, adopting new tools as they emerge in the market to stay competitive. Likewise, regulations around the use of artificial intelligence will inevitably evolve. Marketers need to keep up with these regulations, as well as artificial intelligence best practices, so that they use artificial intelligence responsibly and ethically.

Companies need to have robust policies on the use of artificial intelligence in marketing and other areas to ensure this happens.

5. AI concerns hindering AI adoption in marketing

While AI offers numerous benefits, there are legitimate concerns that may affect its wider adoption in marketing. Here are some key obstacles:

- ✓ *data security*: Marketers manage a large amount of sensitive customer data. AI security concerns, data breaches and data misuse with AI tools can be a significant deterrent;
- ✓ *vague AI regulations*: Legal areas around AI are still evolving. Unclear regulations can create uncertainty and hesitancy around data privacy and consumer rights in AI-enabled marketing strategies, according to 30% of respondents;
- ✓ *lack of AI strategy*: Many companies do not have a clear roadmap for implementing AI. The potential of the technology can remain unrealized without a well-defined strategy [7] that aligns AI with overall marketing goals;
- ✓ *implementation cost/expensive technology*: Advanced artificial intelligence tools can come with a hefty price tag, posing a challenge for companies with limited budgets. According to GetResponse (GetResponse| Professional Email Marketing for Everyone), 35% of respondents are concerned about the cost of AI. In addition, the cost of deployment and integration with existing infrastructure can be a barrier;
- ✓ *skills/training gap*: Effective use of artificial intelligence requires a new set of skills within marketing teams. Moreover, upskilling current employees or recruiting people with expertise in AI and data analytics may require additional investment.

6. Strategies to overcome AI adoption challenges

The power of AI in marketing is undeniable [11]. But addressing the barriers to adoption is critical. Here are key strategies to address these challenges:

✓ *education and training* - marketing teams with the knowledge and skills to work effectively with AI;

✓ *collaboration with AI experts and consultants* - team with artificial intelligence experts for guidance;

✓ *pilot projects and test phases* - implementing pilot projects with specific objectives to test the effectiveness of AI tools in marketing efforts;

✓ *transparency and communication* - openly communicating the benefits and limitations of AI in marketing to all stakeholders. Addressing privacy concerns and fostering a sense of trust in AI implementation is important for successful adoption. [3]

✓ *continuous monitoring and evaluation* - monitoring on a regular basis, analyzing results and adapting strategies as necessary;

✓ *information on evolving AI regulations* - proactively proactively stay abreast of emerging AI regulations, such as the EU AI Act, to ensure compliance and mitigate legal risks. Building a culture of responsible AI use can build consumer trust and promote long-term success. [4]

7. Conclusion

Clearly, artificial intelligence has the potential to improve a company's overall performance and help it grow through more effective marketing campaigns. Remarkably, the technology is still at a relatively early stage of development, so while it's having such a big impact now, in the future it will grow significantly.

However, it is important to be aware of the potential risks in order to establish clear company policies on its use. It is also essential to pay attention to emerging regulations on its ethical and responsible use to remain compliant.

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CHANGES IN CONSUMER BEHAVIOR OF UNIVERSITIES DURING COVID-19 SELF-RESTRAINT PERIOD

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Abstract

The COVID-19 pandemic has forced consumers to refrain from going out, causing changes in their purchasing behavior. Considering the need to examine the impact of COVID-19 on society from multiple perspectives, we examined shifts in consumption patterns among university students before and after the pandemic's onset. The quantitative survey showed that the lifestyles of university students did not appear to have changed much, but the qualitative survey showed a clear division between students whose lifestyles changed before and after the COVID-19 outbreak, and those whose lifestyles did not change at all. These results suggest that the consumption behavior of university students may have been polarized into those who were affected by COVID-19 and those who were not.

Keywords: consumer behavior, university students, online shopping, COVID-19.

JEL Classification: D10

1. Introduction

This study aims to examine how university students' consumer behavior has shifted due to the COVID-19 pandemic. According to Ishihara (2020) [1] of the Statistics Bureau of the Ministry of Internal Affairs and Communications, the percentage of households (two or more persons) using online shopping increased in Japan after April 2020, when the state of emergency was declared following the spread of COVID-19, and reached 50.5% in May, exceeding 50% for the first time since 2002, when the survey began. In June, after the declaration of emergency was lifted, the percentage remained high at 50.8%. Looking at the percentage of households using online shopping by age group, households with heads

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of household in their 30s, 40s, 50s, and 65 and older all increased by more than 10% before and after COVID-19 pandemic.

Not only in Japan, but also in many other countries globally, the impact of the Covid-19 outbreak has forced people to refrain from going out, and the way they shop for groceries and daily necessities has changed drastically. This paper focuses on university students in their 20s in Japan, and analyzes and discusses how their consumer behavior changed before and after the COVID-19 outbreak. Chapter 2 reviews previous studies; Chapter 3 provides an overview of the study; Chapter 4 presents the results of the quantitative analysis; and Chapter 5 presents the results of the qualitative analysis. Chapter 6 provides a discussion, and Chapter 7 presents the conclusions.

2. Review of Previous Studies

Consumers go through several stages of purchasing behavior before deciding on a product or service to purchase. Furthermore, evaluation, disposal, and other actions also occur after purchasing. Figure 1 shows the six stages of the consumer purchasing process (Tanaka, 2008, p.53-54) [2]. This study focuses on (4) purchasing behavior, especially online purchasing behavior.

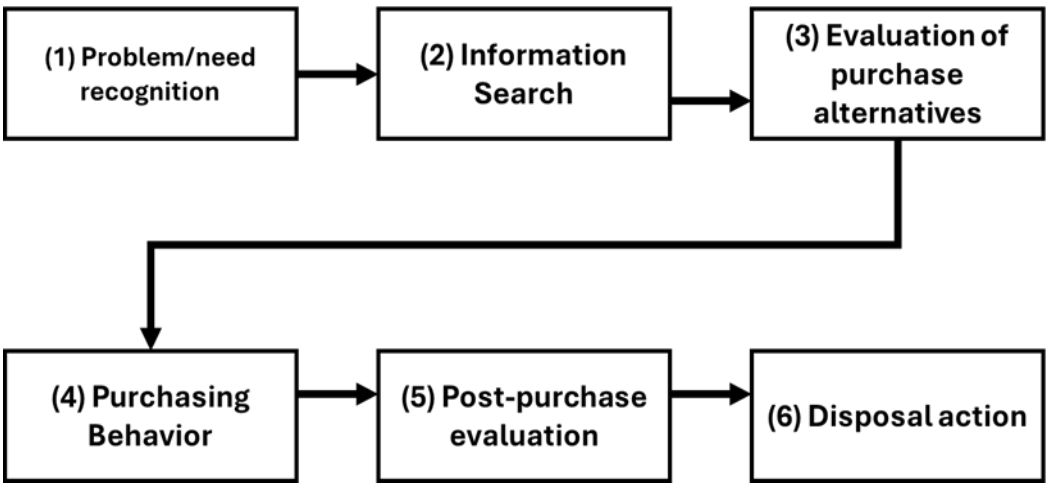

Figure 1: Consumer Buying Process

Nakano and Kondo (2019) [3] noted that consumers who are more likely to make online purchases are associated with consumer characteristics such as buying more daily consumer goods at once, having more time to spare, shopping more frequently, and having fewer children in the elderly female population. Consumers who are more likely to make online

purchases over time are associated with certain consumer characteristics, such as having less time to spare, shopping on weekends, shopping less frequently, and being more price sensitive. Furthermore, they noted that the accumulation of experience using e-commerce sites on computers has a stronger influence on online purchases of daily consumer goods than on mobile devices and that mobile usage is higher as consumers gain experience over time.

Nakamura (2016) [4] noted that the widespread use of smartphones and tablets has led to an increase in consumer purchase behavior, such as making purchases online rather than in physical stores, after seeing and trying out the actual products in stores.

Chocarro, Cortiñas, and Villanueva (2013) [5] noted that the main determinants of consumers' channel choice are related to time and distance, and that distance to stores and time pressure are factors that influence the probability of online purchase.

Thus, various studies have been conducted on changes in online consumer behavior. It is thought that self-restraint from going out of the house further increased online purchases after the COVID-19 outbreak, and in fact, the percentage of households using online shopping increased in Japan, both for households in their 30s, 40s, 50s, and 65 years of age and older (Ishihara, 2020). Because we believe that the impact of COVID-19 on society needs to be studied from various perspectives, this study focuses on the consumer behavior of university students in their 20s immediately after the COVID-19 pandemic.

3. Research Outline

This study was conducted from November to December 2020 as a quantitative survey using a questionnaire survey of 45 university seniors (in their 20s) in Niigata Prefecture, Japan. The total number of valid responses to the questionnaire was 36, of which 27 were valid (24 living alone and 3 living at home). In addition, a qualitative survey was conducted by interviewing eight fourth-year university students (four males and four females) living alone. The reason for focusing on qualitative research on students living alone was that students who live alone have more opportunities to make purchases for food and daily necessities than students who live at home, and thus are more likely to be affected by COVID-19. The time period for this study was February 2019 to January 2020, before the COVID-19 pandemic, and February 2020 to December 2020:after COVID-19 pandemic.

4. Quantitative Research

This chapter describes the content of the questionnaire and the results of the data obtained from the questionnaire survey with the aim of identifying changes in consumer behavior before and after the COVID-19 pandemic.

4.1 Questionnaire

The questionnaire was developed based on a study by Nakano and Kondo (2019). The questions consisted of nine items: number of purchases per month, number of purchases in physical stores per month, number of purchases online per month, number of purchases on holidays per month, number of purchases per month, part-time job salary per month, amount of money sent home per month, time spent on the internet per day, and time spent on e-commerce sites per day. The part-time job salary and amount of money sent home were divided into five levels: 0 yen to less than 25,000 yen, 25,000 yen to less than 50,000 yen, 50,000 yen to less than 75,000 yen, 75,000 yen to less than 100,000 yen, and more than 100,000 yen. For each item, we asked about the average monthly values.

4.2 Questionnaire survey results

	Question	Before pandemic	After pandemic	(After pandemic)-(Before pandemic)
1	Number of purchases per month	15.56	14.56	-1
2	Number of online purchases in a month	2.33	3.07	0.74
3	Number of purchases at physical stores in a month	13	11.07	-1.93
4	Number of holiday purchases in a month	4.44	4.3	-0.14
5	Number of purchases per shopping trip	5.3	5.89	0.59
6	Part-time job salary per month	2.59	2.33	-0.26
7	Amount of money sent home per month	2.04	1.93	-0.11
8	Time spent online per day	6.04	6.56	0.52
9	Time spent using e-commerce per day	1.13	1.222	0.092

Table 1: Comparison of means from the results of the questionnaire.

	Before pandemic	After pandemic	

	Mean *M*	Standard deviation *SD*	Mean *M*	Standard deviation *SD*	t-value
Total number of purchases	15.56	12.509	14.56	12.454	-1.04
Number of purchases	2.33	2.572	3.07	4.169	1.48
Number of online purchases	13	11.28	11.07	9.421	-2.20*
Number of purchases in physical stores	4.44	3.412	4.3	2.972	-0.26
Number of purchases on holidays	5.3	2.839	5.89	3.389	1.23
Part-time job salary	2.59	1.185	2.33	1.271	-0.86
Sending money	2.04	1.192	1.93	1.207	-0.37
Time spent online	6.04	3.458	6.56	3.609	1.01
Time spent on e-commerce	1.13	1.0246	1.222	1.2659	0.32

* $p<.05$ ** $p<.01$

Table 2: Changes in consumer behavior among university students (two-tailed t-test)

Table 1 presents the average results of the questions and responses regarding lifestyle changes. Comparing the difference in means before and after the Pandemic, online purchases per month increased 0.74 times, while the number of actual store purchases per month decreased 1.93 times. However, when a two-tailed t-test was conducted in Table 2, the number of actual store purchases was significant, whereas the number of online purchases was not. For the other items, the difference between the means of the two periods was less than one, and the results of the two-tailed t-test were not significant.

5. Qualitative Research

This chapter describes the questions and results of the interview survey conducted with eight university students in order to conduct a more detailed study using quantitative analysis.

5.1 Question Content

In the qualitative study, eight students were asked the 11 questions shown in Table 3.

(1) Have there been any changes in online shopping use (number of purchases, products purchased) before and after COVID-19 outbreak?
(2) Before and after COVID-19 outbreak, were there any changes in the use of physical stores (number of purchases, items purchased)?
(3) When do you use online shopping?
(4) How much free time do you have on average per day?
(5) When do you do most of your shopping, on weekdays or holidays?
(6) What devices do you use when you shop online?
(7) What sites do you use when you shop online?
(8) What criteria do you use to distinguish between physical stores and online shopping?
(9) What type of part-time jobs do you have?
(10) Have there been any changes in the salaries of part-time workers before and after COVID-19 outbreak?
(11) Is there any change in the distance you travel when you go shopping?

Table 3: List of Interview Survey Questions

The basic questions were the same as those in the quantitative study, but the questions in the quantitative study were asked in more detail. In addition, because Nakano and Kondo (2019) indicated that consumers who purchase online are characterized as having less time to spare, shop on weekends, shop less frequently, and are more price-sensitive, we asked questions regarding (4) the amount of free time they have in a day and (5) the timing of their shopping trips. In addition, as Chocarro, Cortiñas, and Villanueva (2013) showed that the distance from home to a physical store affects online purchasing, we also asked whether the distance to go shopping changed before and after the COVID-19 outbreak (11). The results are presented in Table 1.

5.2 Interview Survey Results

A summary of the interviews with students A through H is presented in Table 4.

	A male	B female	C male	D male	E female	F female	G female	H female
question								
(1) Online purchasing changes before and after COVID-19 pandemic	No change	Frequency increased after the outbreak.	No change	No change	Frequency increased after the outbreak.	No change	Frequency decreased after the pandemic.	No change in frequency after the pandemic, but the frequency increased in June and July.
(2) Changes in purchases at retail stores before and after the COVID-19 pandemic	No change Almost no shopping because they finish their meals at cafeterias	Frequency decreased. Frequency has decreased because they no longer purchase groceries and books.	Frequency has not changed, but use of convenience stores increased during the period of self-restraint.	No change	No change	Frequency has not changed, but has recently increased.	Frequency has decreased since the outbreak.	Frequency has decreased since the outbreak.
(3) Use of	When I want	When I want to	When prices	When prices	When you are	When you are	When you	When you

online shopping	something that is not available in Nagaoka	shop easily and buy something that is not available in Nagaoka	are low and I want to buy something that is not available in Nagaoka	are low and the store does not have the item in stock,	interested in something you saw advertised	interested in something you saw advertised	want to buy something that is only available on the Internet, or when it is cheaper on the Internet	don't need to go out of town to buy something when it is cheaper on the Internet
(4) Free time	2,3 hours before 5,6 hours after	3 hours before 7 hours after	7 hours before 5 hours after	2,3 hours before 3,4 hours after	5 hours before 9 hours after	4,5 hours both before and after	4 hours before 10 hours after	5,6 hours before 10 hours after
(5) Timing of shopping	holiday	Weekdays	Weekdays	Weekdays	Weekdays	Weekdays	holiday	Weekdays
(6) Devices used when shopping online	PC	PC, Smartphone	PC, Smartphone	Smartphone	Smartphone	Smartphone	Smartphone	Smartphone
(7) Sites used for online	Amazon, multiple sites for	Amazon, My Protein	Amazon, My Protein, iHerb	Amazon, multiple sites for	Rakuten, e-commerce of	Instagram ads to EC sites	Amazon	Amazon, Rakuten

shopping	price comparison			price comparison	specific stores			
(8) Use of physical stores and online	Store for items with expiration dates, online for items that are the same no matter where you buy them	If the item you want is in the store, go to the store; if not, go online.	Store for things you need immediately, online for things you don't.	Store for things you need immediately or want to check, internet for things not in stock or not needed immediately	Store for what you need immediately, internet for everything else	Store for redemption, store for hobby items (if not in stock, internet)	Store for food and beverage items, net for books and items not needed immediately	If online is cheaper, use online, otherwise store
(9) Part-time job type	Movie theater	Cram school, gym	Restaurants	Restaurants	Restaurants	Restaurants, cram schools	I don't do it.	Cram school
(10) Salary changes before and after the pandemic	No change (due to absence allowance)	No change	Decreased during the period of self-restraint, otherwise no change	Decreased during the period of self-restraint, otherwise no change	Income decreased	Income decreased (with some absence allowance)		Salary decreased after the pandemic, but not significantly due to absence

								allowance
(11) Change in distance to go shopping	No change	No change	No change	No change	No change	No change	No change	Shopped as close as possible and spent less time outside.

Table 4: List of Interview Survey Results

Four out of eight students changed their online shopping use as a result of the COVID-19 outbreak, with students B, E, G, and H changing, while students A, C, D, and F remained unchanged. Students B, E, and H increased their online shopping use after the pandemic. The reason for the increase in June and July for Student H was that they used online shopping more often as they refrained from going outside because of self-restraint.

Five of the eight respondents showed a change in their use of physical stores, with students B, C, F, G, and H changing, while the others, students A, D, and E, remained unchanged. Students B, G, and H had consciously reduced their use of physical stores due to the COVID-19 pandemic.

The situations in which online shopping is used can be divided into three categories: (1) when purchasing items that are only available online, (2) when the online price is lower than the price of the product in the actual store, and (3) when the customer sees an advertisement and becomes interested in the product. Students A, B, C, and G responded to (1), students C, D, G, and H to (2), and students E and F to (3).

Regarding free time per day, before COVID-19 pandemic, students had relatively little free time due to classes, research, and job hunting. After the pandemic, free time increased except for Student C because classes were held online and he no longer had to commute to school. Student C said that after COVID-19 pandemic, he had less free time because his personal activities increased.

The timing of shopping did not change before or after COVID-19 pandemic, with students B, C, D, E, F, and H indicating that they do it on weekdays. Students A and G indicated that they shopped on holidays.

Regarding the devices used for online shopping, Student A used only a PC, Students D, E, F, G, and H used only a smartphone, and Students B and C used both a PC and a smartphone.

Amazon was the most frequently used e-commerce site, as selected by students A, B, C, D, G, and H. However, depending on the product to be purchased, Student A browses other sites for comparison, and Students E and F purchase brands from e-commerce sites they are interested in through advertisements displayed on social networking sites.

Students E and F tend to purchase items they need immediately at brick-and-mortar stores and purchase items online if they do not need them immediately or if the form and performance are the same regardless of where they buy them. In addition, students B, D, and F indicated that they buy online when the actual store does not have an item in stock, while students F and G indicated that they buy food, beverages, and other items at the actual store.

Regarding monthly income from part-time jobs, differences were found depending on part-time jobs. However, the overall trend was a decrease in income for five out of the eight respondents, indicating that they were affected by COVID-19.

Regarding the distance of stores used, student H, aware of COVID-19 shopped at stores as close as possible, while the other students did not change and made purchases at the same stores.

6. Discussion

Looking at the averages of the quantitative surveys in this study, the total number of purchases per month by university students decreased by 1, the number of online purchases increased by 0.74, and the number of physical store purchases decreased by 1.93 before and after COVID-19 pandemic. Of these, the results of the two-tailed t-test showed that the number of actual store purchases was significant. As for the other items, the mean difference between the two periods was less than 1 for the number of purchases per month on holidays, the number of purchases per shopping trip, part-time job salary per month, the amount of money sent home per month, time spent on the Internet per day, and time spent on e-commerce sites per day, and the results of two-tailed t-tests were not significant. Therefore, looking at the results of the quantitative survey, it appears that there were not many changes in the lives of the university students.

However, looking at the results of the qualitative study, there is a fairly clear division between students whose lives changed before and after COVID-19 pandemic and those whose lives did not. For example, four of the eight students said that online shopping had changed and four said it had not. The former four students also said it had changed, with the exception of one student, when asked about the number of actual store purchases they had made since then.

Nakano and Kondo (2019) pointed out that the characteristics of consumers who make online purchases are related to consumer characteristics, such as buying many daily consumer goods at once, having more time to spare, shopping more frequently, and having

fewer children in the elderly female population. This study could not show the characteristics of university students who made online purchases after the COVID-19 outbreak. We could not show the characteristics of university students' consumer activities in the way Nakamura (2016) and Chocarro et al. (2013) did.

The implication of this study is that, while quantitative research would Equalize the numbers in the form of averages for the consumer behavior of Japanese university students, qualitative research would likely show that Japanese university students were quite clearly divided into two groups: those affected by COVID-19 pandemic and those not affected by it.

Naturally, even among generations other than university students, such as those in their 50s and 60s, there would have been a clear division between those affected and those not affected by the COVID-19 pandemic. However, given that the vaccination rate (third dose) for COVID-19 increased with age as of April 1, 2024, with 55.9% for those in their 20s, 79% for those in their 50s, and 85.2 % for those in their 60s to 64s (Ministry of Health, Labor and Welfare, 2024) [6], it is not surprising that consumer behavior also showed that the older people became, the more uniformly the new type In contrast, those in their 20s were more likely to be affected by COVID-19 than those in their 30s. In contrast, it is possible that those in their 20s were polarized into two groups: those affected by COVID-19 and those not affected by it.

7. Conclusion

The research question for this study was how the consumer behavior of university students changed before and after COVID-19 outbreak.

Based on the results of the quantitative survey in this study, it appears that the consumer behavior of university students did not change much after the COVID-19 outbreak. However, the results of the qualitative study showed a fairly clear division between students whose consumer behavior changed before and after the Pandemic and those whose behavior did not change. This study suggests that after COVID-19 pandemic, the consumer behavior of university students may have been polarized into two groups, those affected by COVID-19 and those not affected by COVID-19.

However, this study has limitations in generalizing the results of this study, since the number of valid responses to the quantitative survey was 27 and the number of interviewees for the qualitative survey was 8. In addition, this study does not address such issues as what polarized the consumer behavior of university students. Furthermore, with regard to COVID-19, there is the question of whether consumer behavior will return to normal when the self-restraint is eased, or whether the behavior at the time of the self-restraint will continue. These issues will be the subject of future research.

Acknowledgments

We would like to express our sincere gratitude to everyone who participated in the questionnaire and interview surveys for this study. This work was supported by JSPS KAKENHI Grant Number 24K05055.

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THE ESG-S IN FINANCE AND ACCOUNTING AS PERCEIVED BY DIGITAL NATIVES – A COMPARATIVE STUDY BETWEEN ALBANIA AND KOSOVO

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Albana KORRESHI[2]

Abstract

As the use of Environmental, Social, and Governance indicators has considerably increased and most recently has been heavily regulated by the authorities, the participants in the market, including companies, regulators, and professionals need to adjust to these developments and adopt the new trends. This study aims to conduct a comparative examination of student perceptions of ESG and CSR-related themes across two countries and determine how they believe this will influence their behavior as future investors, employees and company managers, and customers. Although norms are developing, ethical ESG investing awareness is still in its infancy. The numerous and frequently incompatible ESG statistics and studies must be understood by corporations and investors who want to create ESG products. We made use of an online survey targeting finance students to measure their perceptions and awareness related to the concepts of ESG and CSR. We found that students are not receiving a lot of information on the trending ESG topic in class but are mostly relying on information received over social media. We suggest that the University could enhance its role in this regard by extending the existing curricula to include topics on the matter. The article's main contribution is that it explores the lack of information regarding the level of knowledge on the ESG and CSR topics and may serve as a benchmarking tool for future research in the field in the same countries or other countries of the region.

Keywords: ESG in education, student perceptions, university curricula, CSR

JEL Classification: M40

1. Introduction

In recent years, the landscape of corporate responsibility and sustainable business practices has undergone significant evolution, catalyzed by the burgeoning emphasis on

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Environmental, Social, and Governance (ESG) factors and Corporate Social Responsibility (CSR). These developments have engendered a profound shift in both the internal operations and external reporting standards of numerous enterprises. Finance professionals, tasked with navigating this dynamic terrain, are compelled to adapt to the heightened regulatory scrutiny and evolving governmental mandates worldwide. Notably, the advent of the European Union's Directive on Corporate Sustainability Reporting (CSRD) has augmented the regulatory framework alongside the preexisting Sustainable Finance Disclosure Regulation (SFDR), amplifying the imperative for comprehensive data collection, robust processing methodologies, and transparent reporting mechanisms about non-financial dimensions.

Amidst this transformative backdrop, contemporary students pursuing degrees in economics, management, and finance are urged to cultivate a holistic understanding of the intricate interplay between business processes and information management protocols, encompassing both financial and non-financial realms. This underscores the necessity for academic curricula to integrate comprehensive coverage of ESG and CSR principles, equipping students with the requisite competencies to navigate the complex terrain of sustainable finance effectively.

In light of these imperatives, this study endeavors to undertake a comparative analysis across three distinct national contexts, examining the perceptions of students regarding ESG and CSR considerations, and elucidating their anticipated implications for future behavior as prospective consumers, employees, and investors. Currently underway in Albania and Kosovo, with plans for subsequent replication in Italy to serve as a benchmarking reference, this research endeavors to illuminate the prevailing educational landscape surrounding sustainability within higher education institutions. Preliminary observations suggest that coverage of ESG and CSR topics in university curricula remains nascent in Albania and Kosovo, prompting reliance on alternative information sources such as the internet and social media among students. These observations are particularly pertinent given the digital-native status of contemporary student cohorts, underscoring the potential utility of leveraging innovative technological platforms and educational tools, including mobile applications, to enhance engagement with ESG and CSR themes.

In light of these findings, we advocate for the integration of ESG and CSR topics into university curricula, advocating for pedagogical approaches that harness the intrinsic digital fluency of students to foster deeper engagement and understanding. As the individuals examined in this study transition into future roles as employees, consumers, and investors, the imperative for holistic education surrounding ESG considerations becomes increasingly pronounced, underscoring the imperative for strategic investments in sustainable education initiatives.

2. Literature Review

Numerous scholarly inquiries have directed attention toward students as focal points within the academic realm, shedding light on their perceptions and behaviors vis-à-vis university

practices and corporate social responsibility (CSR). For instance, Gilbert [1] delves into the robust linkage between students and their respective universities, revealing that heightened emotional attachment to the institution correlates positively with a propensity to attribute value to socially responsible initiatives undertaken by the university. Building upon this premise, Suffrin's [2] investigation in 2017 adopts a nuanced approach, exploring how students' perceptions of CSR influence their behavioral inclinations. Notably, Suffrin's findings underscore the pivotal role of CSR perceptions in shaping students' social behaviors, both within their immediate community contexts and as discerning consumers.

Moreover, the seminal work of Burcea and Marinescu in 2011 [3] accentuates the significance that students accord to corporate social responsibility within the academic milieu. Their research illuminates a noteworthy trend wherein students exhibit a keen interest in CSR-related endeavors, as evidenced by their active engagement in activities aligned with this conceptual framework. This propensity for involvement underscores the burgeoning importance that students attribute to ethical and socially conscious organizational practices.

However, despite these encouraging trends, the study by Simic et al. in 2022 [4] presents a sobering perspective on the current state of university sustainability measures as perceived by students. Their findings indicate that universities still have substantial ground to cover in terms of enhancing their approach to sustainability initiatives. As primary stakeholders of the academic institution, students wield considerable influence in shaping institutional priorities and policies. In light of this, universities must heed the evolving preferences and values of contemporary student demographics, particularly the altruistic Gen Z cohort, characterized by a heightened sensitivity towards environmental and social concerns. Recognizing students' heightened emphasis on sustainability, universities must undertake concerted efforts to bolster their environmental and social initiatives to align with the values and expectations of their student body.

Collectively, these scholarly endeavors underscore the multifaceted dynamics inherent within the student-university relationship, emphasizing the pivotal role of students as discerning stakeholders whose perceptions and preferences warrant careful consideration in shaping institutional practices and priorities.

The most comprehensive international survey of students and their ESG perceptions was carried out in 2018 by the National Student Union in the UK [5]. They found that students worldwide show a strong interest in sustainable development and are keen to learn more about sustainable development, but also want to see action by their institution and see it embedded in all courses. Most of the surveyed students say they have experienced some teaching related to sustainable development, however, a quarter says it hasn't been covered at all. Respondents also reflect a strong influence of their studies on their ability to contribute to change. Looking beyond their time in education, respondents show a desire to work for companies that perform strongly concerning sustainable development.

In this respect, our study contributes to analyzing whether the level of knowledge about the ESGs and CSRs is important in determining the behavior of students as potential investors, and current and future customers, not only in connection to the university they attend but as future actors in the market.

In their survey in 2015, the CFA Institute [6] analyzed more than 1300 of their members (portfolio managers and research analysts) to better understand the perceptions of CFA Institute membership concerning ESG issues and ESG data, as well as how members use such information in their investment processes. They found that 73% of survey respondents take ESG issues into account in their investment analysis and decisions, with governance being the most common among the three dimensions. The main reason they do take the ESGs into account is to help manage investment risks and 57% of those considering ESG issues integrate them into the whole investment analysis and decision-making process. The main ways survey respondents get information on ESG topics is through public information, followed by third-party research. Survey respondents indicate the most important ESG issue in their investment analysis/decisions is board accountability, followed by human capital and executive compensation.

Vukasovic [7] in his study in 2013 examined the change within higher education amidst environmental pressures shed light on the trajectory of educational content evolution, particularly highlighting the anticipated integration and standardization of new topics across European institutions as a consequence of globalization. However, Jefford's [8] observations in 2021 challenge the notion that teaching Environmental, Social, and Governance (ESG) principles is as straightforward as teaching basic literacy (ABCs). The complexities surrounding responsible investing, climate finance, impact investing, sustainable finance, and ESG investing underscore the nuanced nature of sustainable finance education. Definitions within this realm often remain ambiguous, mirroring the lack of clarity in standards for corporate sustainability disclosures.

Indeed, the ambiguity and absence of uniform standards not only impact financial markets but also cast a shadow over educational curricula, particularly within the higher education sector. Without a robust and universally accepted framework for reporting ESG metrics, the incorporation of such principles into university courses is hindered. The uncertainty surrounding sustainable finance education necessitates a concerted effort to establish a clear and firm foundation for the integration of ESG topics into academic programs. Only through such standardized frameworks can universities effectively equip students with the knowledge and skills necessary to navigate the complexities of sustainable finance in today's globalized world.

In their 2019 study, Boca and Saracli [9] delved into the intricate relationship between perception, attitude, and environmental behavior among university students across various fields of specialization, including electrical engineering, mechanical engineering, and economics. Their research unearthed compelling insights into the environmental engagement of students undergoing academic training. One of the key findings of their study was the active involvement of students in activities aimed at environmental

protection. These activities ranged from volunteering for environmental initiatives to raising awareness about environmental issues, participating in recycling programs, and embracing the use of new products and alternative energy sources that are more environmentally friendly. Such engagement underscores the proactive stance that students take toward sustainability and environmental stewardship.

Moreover, Boca and Saracli's research illuminated a positive correlation between perception, attitude, and behavior variables concerning the environment. This suggests that students who possess a heightened perception of environmental issues tend to harbor positive attitudes toward environmental conservation, which in turn translates into tangible behaviors geared towards sustainability. This positive relationship underscores the significance of cultivating environmental awareness and fostering environmentally friendly attitudes among university students across diverse fields of study. By shedding light on these interconnected dynamics, Boca and Saracli's study contributes valuable insights to the ongoing discourse on environmental education and sustainability initiatives within academic institutions. It underscores the importance of integrating environmental literacy into various disciplines and fostering a culture of environmental responsibility among future professionals. Ultimately, their findings advocate for a holistic approach to environmental education that transcends disciplinary boundaries and empowers students to become agents of positive environmental change in their respective fields and beyond.

In their 2022 discourse, McReynolds [10] advocates for a strategic shift in university priorities in response to the dual challenges of digitalization and environmental change. Central to her argument is the imperative for higher education institutions to pivot their focus toward cultivating the next generation of leaders equipped to navigate and address the complex demands of the modern world. McReynolds posits that a key avenue for universities to fulfill this mandate is by placing a heightened emphasis on preparing students for leadership roles characterized by a strong understanding of Environmental, Social, and Governance (ESG) principles. She underscores the importance of integrating ESG considerations into various facets of academic life, from research and thesis development to training programs and professional development initiatives. By encouraging greater research into ESG business implementation, fostering the development of comprehensive theses exploring ESG-related topics, and providing rigorous training in ESG principles, universities can equip students with the requisite skill sets demanded by today's evolving workforce. Moreover, McReynolds emphasizes the importance of forging collaborative partnerships between academia and industry to nurture a pipeline of talented individuals poised to assume ESG leadership roles within the corporate sphere.

McReynolds identifies a significant opportunity for higher education institutions to leverage their resources and expertise in tandem with industry stakeholders to cultivate a cadre of motivated and skilled students primed for impactful careers in ESG-focused roles. By harnessing the collective power of academia and industry, universities can play a pivotal role in shaping the trajectory of sustainability efforts and driving positive change on a global scale. In essence, McReynolds champions a proactive approach to higher education that not only responds to the pressing challenges of the present but also anticipates and prepares for the demands of the future. By prioritizing the development of tomorrow's ESG leaders,

universities can fulfill their mandate as engines of innovation and progress, ushering in a new era of sustainability-driven leadership and stewardship.

In their collaborative research, Sheehan et al. [11] present a compelling argument regarding the pivotal advocacy role that accounting students will assume as future corporate leaders. They highlight a significant challenge faced by these students: the prevailing notion that shareholder value should not be compromised to mitigate the externalized environmental and social costs generated by corporations. This entrenched perspective poses a barrier to effectively addressing sustainability concerns within corporate decision-making processes.

Through their study, Sheehan et.al., shed light on the critical need for a paradigm shift in accounting education. They contend that traditional instructional approaches have failed to equip accounting students with the requisite skills and mindset to navigate the complexities of Environmental, Social, and Governance (ESG) considerations within corporate contexts. The persistent adherence to shareholder value maximization as the paramount objective perpetuates a narrow focus on short-term financial gains at the expense of long-term sustainability. To address this gap, Sheehan et al. advocate for the development and implementation of a novel Environmental, Social, and Governance (ESG) Learning Model within accounting curricula. This innovative approach aims to empower accounting instructors to cultivate a deeper understanding of "threshold concepts" among students — fundamental principles that, once grasped, facilitate a transformative shift in mindset and behavior.

By integrating the ESG Learning Model into accounting education, instructors can effectively challenge traditional notions of shareholder primacy and instill a broader awareness of the interconnectedness between financial performance, environmental stewardship, and social responsibility. This holistic approach not only equips students with the analytical tools to assess the true costs and benefits of corporate actions but also fosters a sense of ethical responsibility and advocacy for sustainable business practices. In essence, Sheehan and her co-authors underscore the imperative for accounting education to evolve in tandem with the changing demands of the business landscape. By embracing the principles of sustainability and embedding them into the fabric of accounting pedagogy, universities can empower future corporate leaders to drive meaningful change and contribute to a more equitable and sustainable global economy.

The literature review reveals the lack of studies focused on the students' perceptions and expectations in the target countries, Albania and Kosovo, in the Western Balkans related to the concepts of ESG awareness. As the current students are considered to be Digital Natives, as they have been heavily exposed since their early childhood to technology, this study encompasses this generation to assess their level of interest and awareness. Moreover, as the current students will be the future investors, managers, CEOs, and customers, their perceptions will shape the landscape of ESG practices, regulations, and awareness.

3. Data Collection and Methods

We gather the primary data for the empirical study through a survey delivered at the same time (February and March 2023) to students of master studies at the University of Tirana and the University of Pristina[3]. The survey was run online through the easy-feedback.com platform and was delivered to students through teaching platforms (Microsoft Teams, Moodle platforms, and university emails). The survey was piloted in an initial testing phase and several improvements were made regarding the language used, the number and conciseness of the questions, and the general description of the purpose of the study. The targeted students were students attending master-level courses in either economics, finance, and/or management, implying they have already completed a bachelor's degree in management, business, and economics-related fields in the same universities, which qualifies them to be respondents in this survey.

The students were motivated to complete the survey by explaining to them during classes the importance of studying such a topic and boosting their interest in ESG-related courses and modules. Overall, the feedback received by the authors of the study, and by the students when explaining to them the purpose of the survey, was encouraging and helpful in improving the survey questions and organization before it was finally sent for ultimate completion.

The survey is organized into several closed-ended questions with a five-degree Lickert scale and students were required to state the score they agreed or did not agree, with certain statements related to the depth of their knowledge on various ESG and CSR topics, the source of receiving such information, and the perceived impact such knowledge has on their attitude and behavior toward companies demonstrating various levels of engagement in CSR and ERSG practices.

The methodology consists of the analysis of each question in the survey and a cross-comparison between results measured at the University of Tirana and the University of Pristina aiming to conclude differences in university-offered courses.

4. Results and Discussions

In both countries analyzed (Albania and Kosovo), we found that the respondents, being master students, are more than 95 % younger than 25 years old, thus representing the Digital Natives generation very reliably. Almost half of them were employed at the present or have been employed in the past, whereas the other half have never been employed, again reflecting the normal expectation for master-level students. More than 60 percent of the respondents stated that they have been involved in at least one volunteer activity during the past, demonstrating a high level of sensitivity and awareness to social issues, making them a good sample to test the perceptions on ESG topics in university curricula and beyond.

[3] The survey will later be applied at the Universities in Italy to perform a broader comparative cross-country analysis

The aim of the questionnaire was carefully explained to the students, possibly making a live announcement while in the class, and taking time to discuss their questions or unclarities. The first set of questions in the survey aimed to gather information related to the depth of knowledge of the respondents on various topics of ESG and CSR such as green bonds, conservation finance, greenwashing, etc. We found that, for students at the University of Tirana, topics such as green bonds and sustainable finance are the most familiar to them, while Greenwashing, the newly introduced International Sustainability Reporting Standards, and the Corporate Sustainability Reporting Directive were vastly unfamiliar to them.

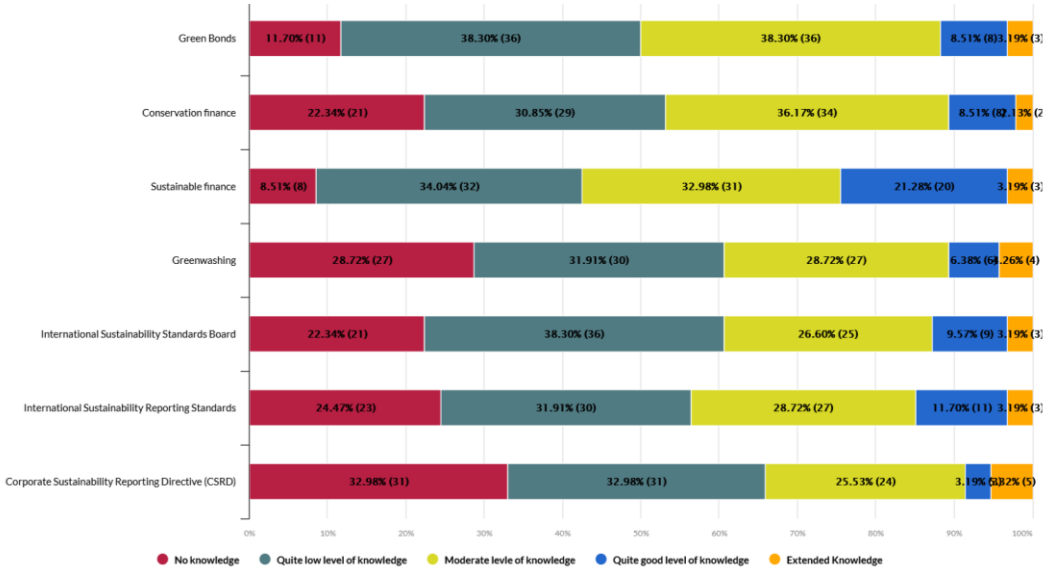


Figure 1. The level of knowledge related to various topics of ESG and CSR (University of Tirana)[4]

As a comparison, students at the University of Pristina, are more familiar with sustainable finance, conservation finance, and the International Sustainability Reporting Standards.

[4] Source: Authors' data analysis

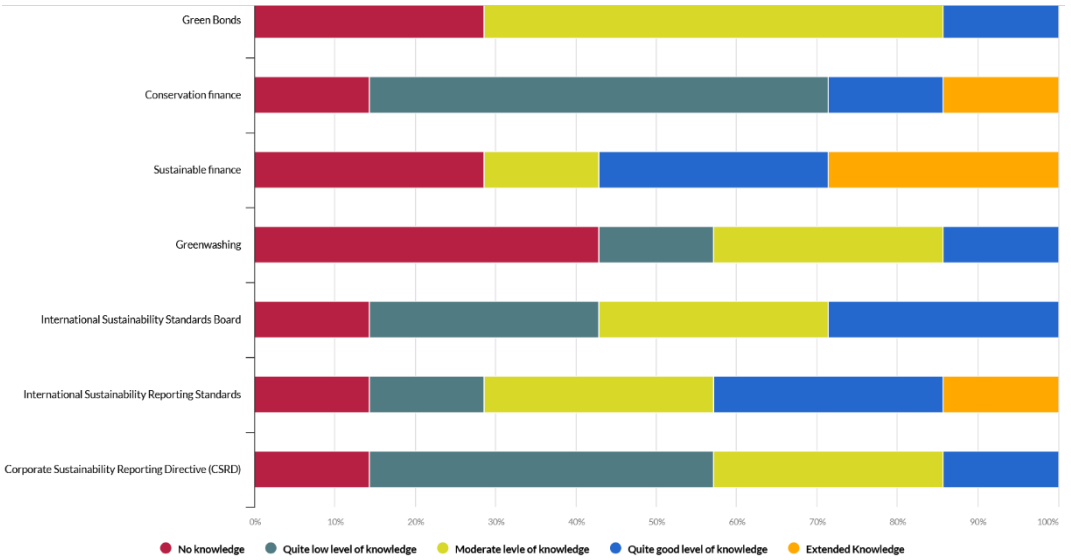
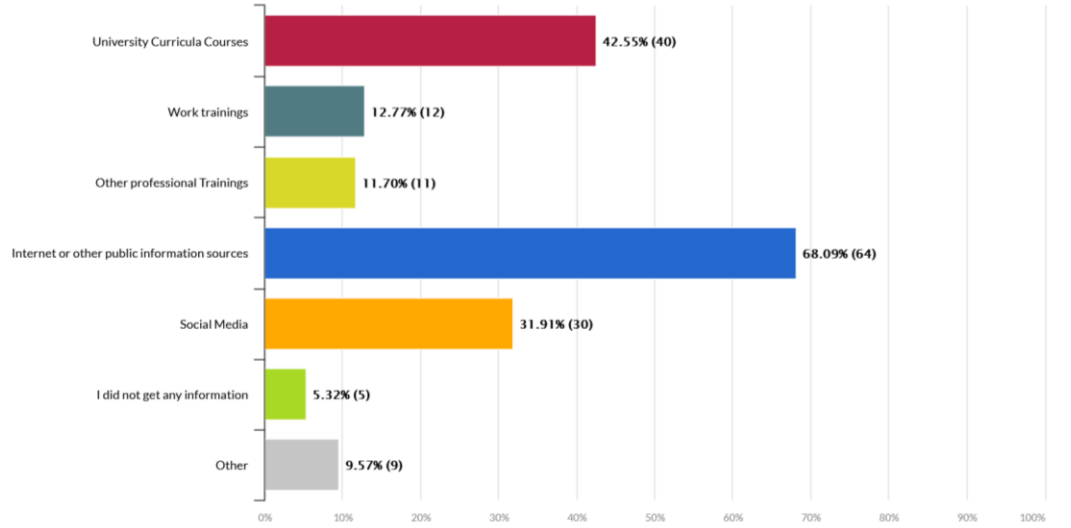


Figure 1.1. The level of knowledge related to various topics of ESG and CSR (University of Pristina)[5]

Next, students were asked to state the source from where they mostly derived information and knowledge on the above topics. We see a very clear difference between both countries here; at the University of Tirana, the courses offered as part of their studies were chosen in less than half of their answers as a source of information on topics on ESG and CSR. The most likely source of information was the internet and other public information, one feature already expected for the Digital Natives generation, but still reveals the low level of reflecting such topics in university studies.



[5] Source: Authors' data analysis

Figure 2. The source of information for various topics of ESG and CSR (University of Tirana)[6]

In contrast to that, we can see that at the University of Pristina, the main source of information was the courses offered at the university itself and after that, work training. This finding reveals the main difference between both universities and the content and topics they offer via their curriculum. We witness a far more advanced coverage of ESG and CSR topics at the University of Pristina, which the University of Tirana could learn from.

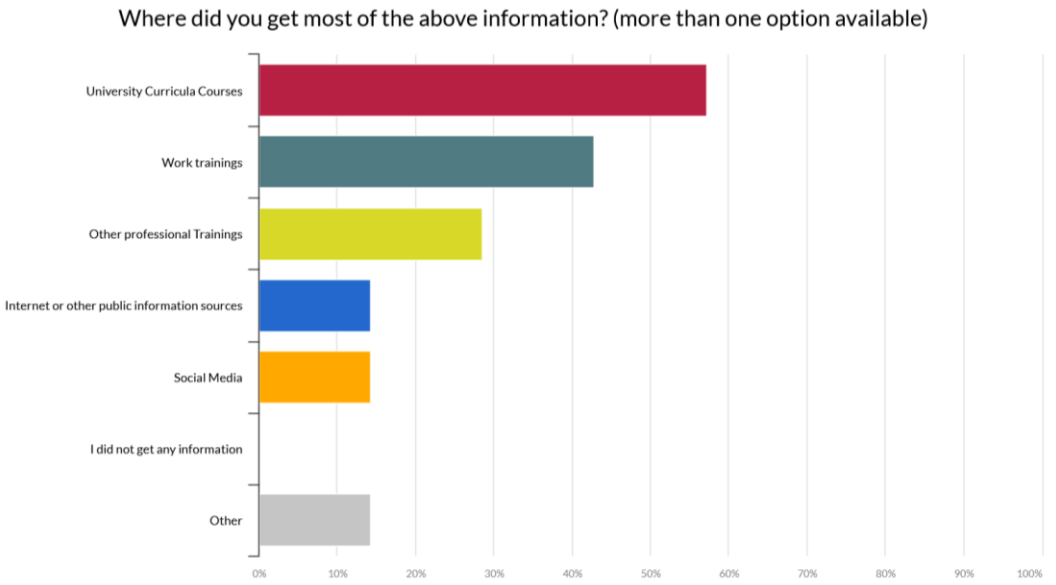


Figure 2.1. The source of information for various topics of ESG and CSR (University of Pristina)[7]

In the next section of the survey, we aimed to investigate the attitude the students were likely to demonstrate if they were in the position of a "potential investor", "customer", "employee", "general public" or "student". Less than 35% of the students stated that they could not distinguish features of the engagement of an entity in ESG and/or CSR activities, thus validating their following answers. We find that as customers, employees, and general public individuals, the students at the University of Tirana demonstrate a high sensitivity as to whether to engage with a firm that has a plan or ESG measures in place. Especially, in

[6] Source: Authors' data analysis
[7] Source: Authors' data analysis

the role of students, they agree to have more information on ESG and CSR topics included in the university courses.

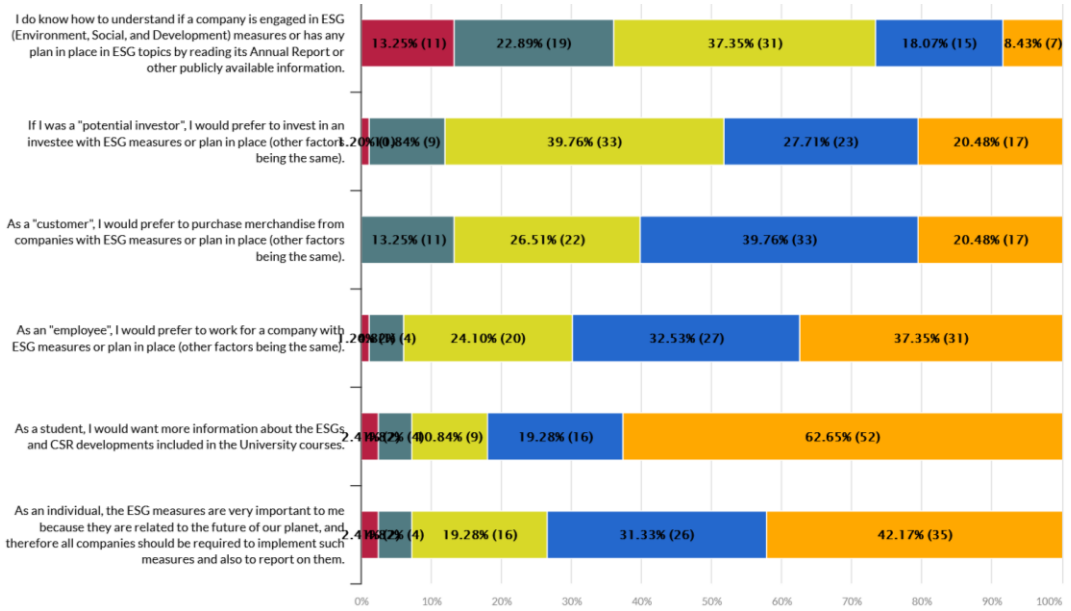


Figure 3. The attitude in various roles towards ESG plans and measures (University of Tirana)[8]

The landscape is much different at the University of Pristina where the majority of the students are well aware of their role as future employees, investors, or customers. 40% of them know "very well" or "well" how to read and understand whether an entity is engaged in ESG plans, compared to only 26% from the University of Tirana. Visually it is clear that at the University of Pristina, results are skewed in favor of students agreeing or fully agreeing to prefer entities engaging in ESG plans rather than entities without such plans, (figure 3.1).

[8] Source: Authors' data analysis

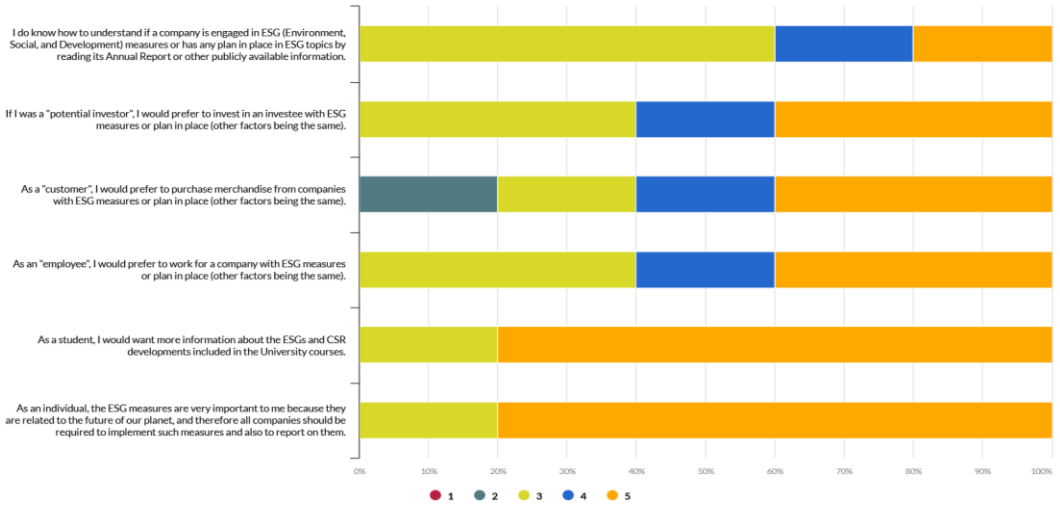


Figure 3.1. The attitude in various roles towards ESG plans and measures (University of Pristina)[9]

At the next step, we wanted to ask the students how much they think that university studies have helped to raise awareness towards ESG topics and form their current attitude towards such values. As expected, we find a low impact of university courses in such an attitude (with less than 25% of the respondents choosing a scale of 8 or above, 10 being the maximum) at the University of Tirana (figure 4), and a high impact at the University of Pristina (figure 4.1).

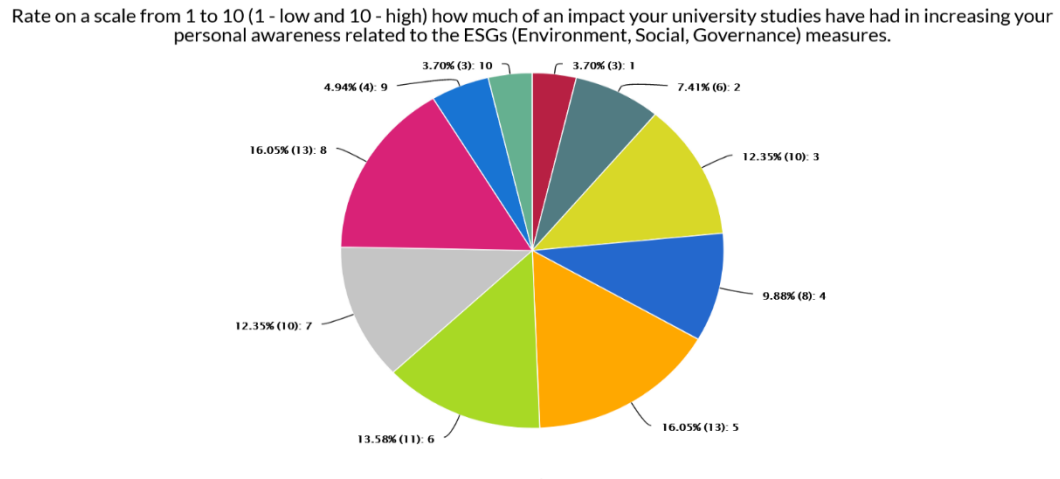


Figure 4. The impact of university studies in increasing the awareness towards ESG measures (University of Tirana)[10]

[9] Source: Authors' data analysis
[10] Source: Authors' data analysis

Figure 4.1. The impact of university studies in increasing awareness towards ESG measures (University of Pristina)[11]

The next set of questions of the survey focused on ranking various topics of ESGs and CSRs as to their level of importance and the possibility of including or extending them in university courses. Students' perceptions were analyzed yielding the following results. We understand that at the University of Tirana, students want more information on topics such as sustainability auditing, CSRD, and Green bonds (figure 5), whereas, at the University of Pristina, sustainability auditing and environmental finance are the topics of most interest (figure 5.1).

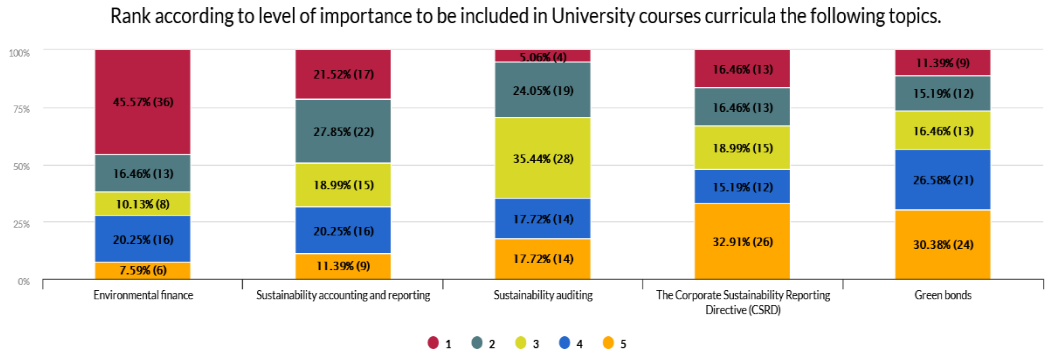


Figure 5. The importance of various topics to be included in university curricula for deeper study (University of Tirana)[12]

[11] Source: Authors' data analysis
[12] Source: Authors' data analysis

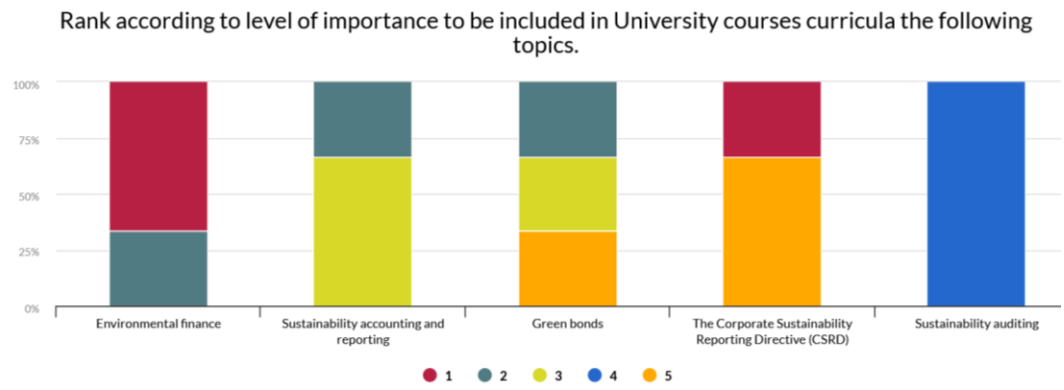


Figure 5.1. The importance of various topics to be included in university curricula for deeper study (University of Pristina)[13]

Other topics that were deemed important for the students were listed in the next section of the survey which included an open-ended question. Recycling, finance culture, gender budgeting, long-term investments in sustainable economic activities and projects, and Basics of Sustainability Accounting were some of the topics that we encountered more often as perceived as important by the respondents.

5. Conclusions and Recommendations

The focus of this paper is to perform a comparative study of the perceptions of master-level students across three countries, Albania, Kosovo, and Italy where the latter will serve as the benchmarking sample when carried out at a later stage. The university courses in Albania and Kosovo have been moderately slow to introduce topics related to ESG and CRS, but as these topics are increasing in relevance, it is important to tackle them through university curricula to raise awareness of the Digital Natives generation.

We find that students at the University of Tirana have limited knowledge related to ESG topics and most of their information is (unfortunately) coming not from university sources, but from the internet and other public sources (social media included). In contrast, students from the University of Pristina demonstrate a higher level of acquaintance and knowledge of ESGs and CSR topics and state that the main source of information for them is the university curricula and sources. Nevertheless, students from both universities demonstrate openness to have these topics included in their university studies and also appear to be sensitive to ESG plans or measures in firms if they take the assumed role of potential investors, customers, or employees in these firms.

[13] Source: Authors' data analysis

We suggest that the inclusion of ESG and CSR topics in university curricula is a must and taking into consideration the features of the Digital Natives and their approach to technology, we suggest that this is done through some innovative teaching method, such as apps or online simulation.

This study is limited in several ways like the small number of observed students across the three countries, the simple methodology, and the timing of observation. We suggest that in the future this study will be extended to include more students and to deploy a more advanced methodology. Also, the extension of the study to find out the right technological teaching methodology would be an added value to improving the teaching process of environmental finance in universities.

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BRINGING NLP TO JAVA CODING - CHATGPT CODE DEVELOPER

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Abstract

The integration of ChatGPT, a state-of-the-art NLP (Natural Language Processing) model developed by the company OpenAI, with the Java programming language provides significant advancements in coding generation and software development. ChatGPT has the ability to generate useful and correct, human-like, text responses, a fact that offers developers a robust tool for automating tasks such as code generation, documentation, error diagnosis, and test case creation. Java, renowned for its extensive ecosystem and backend capabilities, is an ideal choice for leveraging ChatGPT's potential. This paper explores methodologies and best practices for integrating ChatGPT with Java, focusing on API interaction, error handling, and performance optimization. Developers can employ HTTP libraries such as OkHttp and frameworks like Spring Boot to create intelligent and scalable applications. By dynamically generating prompts, integrating with databases, and caching frequent responses, developers can enhance the efficiency of their applications. However, limitations remain, such as the need for manual intervention in resolving library version conflicts and addressing complex tasks beyond AI's current capabilities. Real-life use cases discussed include generating Java code, translating programming languages, enforcing code styles, and supporting real-time applications. Despite occasional inaccuracies in AI-generated outputs, ChatGPT's speed and versatility make it a valuable assistant for both novice and, mostly, experienced developers. The paper concludes by emphasizing the need to experiment with AI-driven tools to maximize productivity and stay abreast of technological advancements in software engineering. As there is no way back to a time without AI support, developers should embrace the new paradigm of assisted programming languages code generation and make the best out of the new environment, while remaining focused on any new relevant developments in this field.

Keywords: ChatGPT integration, java development tools, ai-assisted programming, code automation, NLP in coding

JEL Classification: C8, O39

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1. Introduction

The current time is probably one of the most important and mind-startling occurrences in the field of software development since its inception. Today, the programmer is not alone anymore, or together with his team-mates, he can have a permanent assistant, very smart and educated, in the form of a modern AI prompt-conversation solution. Surely the best known and widely recognized NLP model (Natural Language Processing) application and also one of the most versatile tools of its kind is the ubiquitous ChatGPT, developed by the company called OpenAI. The ability of the NLP to generate human-like text answers transforms it into a very attractive and useful option for software developers looking to integrate such AI-driven conversational agents into their software applications. Java, as one of the most widely used and powerful programming languages today, offers a lot of robust capabilities for backend development, making it a very suitable choice for integration with the ChatGPT tool. This paper present various methodologies and best practices for using Java to interact with ChatGPT, enabling the creation of intelligent, scalable applications.

With this article, I want actually to encourage the use of this technology in our everyday work or at least give it a try in order to make sure that you understand its possibilities, and its shortcomings.

ChatGPT can significantly improve the performance of a developer. It can generate different prototypes and it can help save our time for more complex things than writing basic boilerplate code.

There is quite a hype right now around the ChatGPT NLP technology, but this is still hype mixed with reality. In order to demystify the AI we need to train ourselves and even force ourselves to start implementing AI support in our daily workloads. This is a fact indeed easier said than done, mostly because we are in fact not used to relying on the support of the AI assistance… or not yet anyway. We need to experiment first in order to find the most useful and practical use cases, the cases and scenarios when we can apply it to practice with the most success.

2. Understanding ChatGPT API

To effectively utilize the ChatGPT API, developers should have a foundational understanding of RESTful principles and how they apply to modern API design. This includes knowledge of HTTP methods like GET, POST, and DELETE, as well as understanding the importance of structured data formats like JSON for sending and receiving data. Familiarity with tools like Postman or cURL can also prove invaluable for testing API endpoints during the development process. By mastering these basics,

programmers can ensure seamless integration and debugging when working with the ChatGPT API.

Another critical aspect to consider is the proper handling of API responses. Developers must account for the various response codes the API may return, such as 200 for success, 400 for bad requests, and 429 for exceeding rate limits. Implementing robust error handling ensures the application remains functional even during unexpected scenarios. Furthermore, understanding the structure of the response payload is essential for extracting useful data, such as the generated text or metadata, and transforming it into actionable insights for the application.

Lastly, managing API security is paramount to protect sensitive data and prevent unauthorized access. Developers should adopt best practices like storing API keys securely in environment variables or using secret management solutions. Regularly rotating API keys and monitoring their usage can also mitigate the risk of exploitation. Additionally, adhering to OpenAI's usage policies and implementing user authentication mechanisms when exposing ChatGPT-powered features helps maintain compliance and trustworthiness in production environments.

In this section we will briefly list the basic knowledge a programmer must have before enrolling his AI assistant for writing support code in Java.

The ChatGPT API, offered by OpenAI, actually provides a RESTful interface for developers to interact with the model. By sending HTTP requests with appropriate parameters, developers can obtain responses from ChatGPT to build features like chatbots, text summarization tools, or content generators. Key aspects of the API include:

1. Endpoints: The API typically offers endpoints for generating text, retrieving models, and managing sessions.
2. Authentication: Access to the API requires an API key, which serves as a credential for authorized usage.
3. Rate Limiting: OpenAI enforces rate limits to ensure fair usage, which developers need to account for in their applications.

3. Setting Up a Java Environment

Before integrating the ChatGPT tool into our development environment, it is essential that the we set up the Java development environment correctly. Among the necessary steps for these end we can include:

1. Installation of Java - the developer should ensure that the Java Development Kit (JDK), version 8 or higher is installed.
2. Building Tools - the developer should use recognized tools, such as Maven or Gradle, to manage the dependencies and build the project.
3. HTTP Libraries – the developer should include libraries such as Apache HttpClient, OkHttp or Spring RestTemplate in order to handle HTTP requests.

Below, we can see a source-code example for a Maven dependency with OkHttp:

```
<dependency>
    <groupId>com.squareup.okhttp3</groupId>
    <artifactId>okhttp</artifactId>
    <version>4.10.0</version>
</dependency>
```

3.1. Making API Calls

The Java programming language provides the developers with lots of libraries for making HTTP requests. Below we can see an example of such a case, by the use of the same OkHttp library:

```
import okhttp3.*;
import java.io.IOException;
public class ChatGPTIntegration {
    private static final String API-URL = "https://api.openai.com/v1/completions";
    private static final String API-KEY = "ChatGPT_api_key";
    public static void main(String[] args) throws IOException {
        OkHttpClient client = new OkHttpClient();
        String jsonRequest = "{" +
            "\"model\": \"gpt-4\"," +
            "\"prompt\": \"Hello, what can I do for you today?\"," +
            "\"max_tokens\": 150" +
        "}";
        RequestBody body = RequestBody.create(
```

```
        jsonRequest, MediaType.parse("application/json")
    );
    Request request = new Request.Builder()
        .url(API-URL)
        .addHeader("Authorization", "Bearer "+API-KEY)
        .post(body)
        .build();
    Response response = client.newCall(request).execute();
    if (response.isSuccessful()) {
        System.out.println(response.body().string());
    } else {
        System.err.println("Request failure: " + response.code());
    }
  }
}
```

3.2. Parsing Responses

Responses received from ChatGPT are generally returned in the ubiquitous JSON format. Libraries like Jackson or Gson can be used to parse these responses and transform them into Java objects, usable further for out applications.

Below we can see an example using Jackson:

```
import com.fasterxml.jackson.databind.ObjectMapper;

String responseBody = response.body().string();

ObjectMapper mapper = new ObjectMapper();

ChatGPTResponse chatResponse = mapper.readValue(responseBody,
ChatGPTResponse.class);

class ChatGPTResponse {
  public String id;
  public String object;
  public List<Choice> choices;
```

```
    static class Choice {
        public String text;
    }
}
```

3.3. Handling Errors and Rate Limits

When working with ChatGPT, robust error handling ensures that your application can gracefully recover from different issues. Key scenarios to handle include:

1. Timeouts: Implement retry mechanisms with exponential backoff.
2. Invalid Responses: Validate JSON responses to prevent processing invalid data.
3. Rate Limits: Monitor API usage and implement logic to pause or limit requests when nearing rate limits.

Example error handling code:

```
try {
    Response response = client.newCall(request).execute();
    if (response.isSuccessful()) {
        System.out.println(response.body().string());
    } else {
        System.err.println("API error: " + response.code());
    }
} catch (IOException e) {
    System.err.println("Network error: " + e.getMessage());
```

3.4. Advanced Use Cases

1. Dynamic Prompt Generation: Java applications can dynamically construct prompts based on user input, enhancing personalization.
2. Integration with Databases: Store and retrieve conversational histories in relational databases like MySQL or NoSQL databases like MongoDB.
3. Real-Time Applications: Use frameworks like Spring Boot to create real-time chat applications powered by ChatGPT.

Below we can see an example of integrating with Spring Boot:

```
@RestController
@RequestMapping("/chat")
public class ChatController {
    @PostMapping("/ask")
    public ResponseEntity<String> askChatGPT(@RequestBody String userInput) {
        // Use OkHttp or RestTemplate to make API call
        // Return the ChatGPT response
        return ResponseEntity.ok("ChatGPT Response");
    }
}
```

3.5. Optimizing Performance

Effective performance optimization requires careful planning and implementation of concurrency strategies. When handling multiple users, leveraging thread pools can help efficiently manage system resources and prevent overloading. Asynchronous request handling further enhances performance by allowing the system to process multiple requests simultaneously without blocking threads. For example, the use of Java CompletableFuture or of the reactive frameworks like Project Reactor or RxJava can quite significantly improve throughput and reduce response times in high-traffic applications.

In addition to concurrency, caching plays a vital role in reducing the load on APIs and improving user experience. Implementing a robust caching mechanism, such as using libraries like Ehcache or Redis, allows applications to store frequent responses locally or in-memory. This reduces the number of redundant API calls, thus saving bandwidth and decreasing latency. However, developers must also consider cache invalidation strategies to ensure that the application serves accurate and up-to-date information. Balancing these techniques with thorough load testing using tools like Apache JMeter or Gatling helps simulate real-world usage patterns, identify bottlenecks, and optimize the application's scalability under heavy traffic conditions.

Performance optimization is crucial when integrating with APIs. Summarizing, the main lines regarding the possibilities to optime performance go along the below topics:

1. Concurrent Requests: Use thread pools or asynchronous requests for handling multiple users.
2. Caching Responses: Cache frequent responses in order to reduce the number of API calls and to improve response time.
3. Load Testing: Use tools like JMeter or Gatling to simulate and test application load.

3.6. Security Considerations

The most relevant and widely used topics in regards to security considerations are listed below:

1. API Key Management: Never hard-code API keys. Use secure storage solutions like AWS Secrets Manager or environment variables.
2. Data Privacy: Ensure compliance with data protection regulations by anonymizing sensitive user data.
3. Secure Communication: Use HTTPS for all API interactions.

4. Real-life use cases for ChatGPT in daily Java development

4.1. Code generation

ChatGPT was originally created as a language model. Due to this fact, it is basically meant for reading text and producing text. Programming language code, Java in our case, is a subtype of the text, so ChatGPT can understand issues related to it and generate this type of text also [1].

At this time the entire world is changing, in more than one way and at many levels, and we should not actually resist those changes but in fact embrace them and make the best of it [2]. We can use the newly opened possibilities to improve our productivity. The current situation is not actually something completely new for mankind – even though it had different faces throughout history – scientific progress was always entangled with the fear of losing jobs. Nevertheless, humankind was always able to adapt and this time it will be no different – there are even more types of jobs coming to implement all the AI capabilities that we are being offered in our current environment [3].

ChatGPT can generate Java programming language code based on the natural language input (prompt). As an example, one software developer can just enter/prompt a quite short description of the code he needs, and ChatGPT will try to generate the corresponding code,

written in Java, to solve the request. This scenario can save developer time and reduce the chance of (some) errors in the code.

For example, we can use the below prompt:

Prompt: Generate a JPA model for Student, University and School.

For this request, ChatGPT understands that it should define a Many-To-One relationship between University, School and Student. Also, it defines properties, for example, university name, school name, student's First_Name and Last_Name - elements we did not purposely ask for, but these elements were in reality included within the response. This fact shows that ChatGPT can deliver the missing parts of its task by understanding a somewhat complex context.

The result of the previously mentioned prompt session with ChatGPT is available in the below Figure 1.

```java
import javax.persistance.*;
@Entity
@Table(name = "student")
public class Student{
    @ID
    @GeneratedValue(strategy = GenerationType.IDENTITY)
    private Long id;

    @Column(name = "first_name")
    private String firstName;

    @Column(name = "last_name")
    private String lastName;

    @ManyToOne
    @JoinColumn(name = "school_id")
    private School school;

    //get and set functionality
}

@Entity
@Table(name = "school")
public class School {
    @Id
    @GeneratedValue(strategy = GenerationType.IDENTITY)
    private Long id;

    @Column(name = "name")
    private String name;

    @ManyToOne
    @JoinColumn(name = "university_id")
    private University university;

    @OneToMany(mappedBy = "school")
    private List<Student> students;

    //get and set functions
}

@Entity
@Table(name = "university")
public class University {
    @Id
    @GenerationValue(strategy = GenerationType.IDENTITY)
    private Long id;

    @Column(name = "name")
    private String name;

    @OneToMany(mappedBy = "university")
    private List<School> schools;

    //get and set functions
}
```

Figure 1. This is the illustration of the dialog with Chat GPT

4.2. Documentation generation

The ChatGPT tool is able to also generate documentation for our Java code. This is done based on the Java code itself (perhaps provided by ChatGPT also) and on any other comments or annotations relevant for this purpose. This approach can not only help developers in order to create more complete and accurate documentation, without the need to write it by themselves, but it is also incomparably faster.

For example, we can use the below prompt:

Prompt: For the above generated code please generate documentation

4.3. Test case generation

ChatGPT can generate test cases for Java code based on natural language input. For example, a developer can describe a desired test case, and the model will generate the corresponding Java code. This can save developer's time and ensure that the test cases are comprehensive and accurately reflect the desired behavior of the code.

For example, we can use the below prompt:

Prompt: For the above generated code please generate Unit / BDD tests

4.4. Error diagnosis

The ChatGPT tool can also help Java developers to diagnose potential errors in their Java code. For example, one developer could provide a model-code and a description of the encountered error, waiting for the model to propose different possible solutions to mitigate the issues it finds.

For example, we can use the below prompt:

Prompt: For the above generated code please find the errors in the code

4.5. Error diagnosis

ChatGPT can help Java developers diagnose errors in their code. For example, a developer can provide a model with a description of the error, and the model will suggest possible solutions. Of course, the ChatGPT proposals are not 100% sure and for any complex task the bulletproof solution is actually based on experienced programmers/developers.

For example, we can use the below prompt:

Prompt: For the above generated code please find the errors in the code

4.6. Language translation

The ChatGPT tool can be used as a "translator" between two different programming languages, transforming itself into a valuable help for reusing previously coded algorithms available into a different coding language.

For example, we can use the below prompt:

Prompt: For the above generated code please translate it into the language C# language

4.7. Code style enforcement

The ChatGPT tool is also able to be used to enforce code style standards by suggesting changes to the Java code in order to make it more consistent with a certain style guide that we want to strictly adhere to.

For example, we can use the below prompt:

Prompt: For the above generated code please validate that all constants are upper-cased

5. And… is not exactly working! Why?

For the time being, at least, developers must verify everything that is generated with the ChatGPT tool very carefully [4]. The code generated with ChatGPT's help is often non-functional or is based on several wrong assumptions and it works but in unexpected ways [5]. As a consequence, in real-life, the code generative tool is not, at least yet, a complete replacement for an experienced (senior or at mid-tier) developer. Specialists consider that the quality of the generated code is actually similar to a junior developer's one generally, while the code generation speed is obviously much higher than any human could possibly do.

There are two most frequent reasons for this failure to work out of the box – or out of the generative prompt to be more precise.

1. GPT is in fact based on previously existing programming language code available on the internet. This code might quite often be using different versions of the same libraries. For example, a section of code might uses library L version X, and another section of code might be using the same general library L but version Y. These different variants can be incompatible, at least to a certain degree, but the ChatGPT tool does not has the understanding and it produces a mix of different versions implemented in the same proposed code. The developer can ask the tool to use only

a certain version of a certain library but this is not a guarantee; in some cases the results will be better, in other cases there is no difference. If the more specific request does not help the developer has to actually check for incompatibilities manually and make all the possible necessary changes.

2. In some scenarios, the task send to the ChatGPT tool can be too complex for it. In such a case it would in fact be possible to split the task into several subtasks, but this operation is quite often too difficult for the current implementations of NLP. Such a complex task is currently beyond the features and capabilities of the publicly available AI, but this might change in future versions quite fast.

6. Conclusions

Integrating ChatGPT with Java opens a plethora of possibilities for building intelligent and efficient applications. By following best practices and leveraging Java's rich ecosystem, developers can harness the power of AI to deliver innovative solutions. This combination not only enhances user experience but also provides a scalable approach to addressing complex challenges in software development.

The integration of ChatGPT with Java represents a paradigm shift in software development, combining artificial intelligence and robust backend capabilities to revolutionize coding workflows. By leveraging ChatGPT's API, developers can streamline tasks such as code generation, error diagnosis, and documentation creation, allowing them to focus on complex problem-solving. The methodologies outlined, including API interaction, error handling, and performance optimization, empower developers to build intelligent, scalable, and efficient applications.

Despite its remarkable capabilities, ChatGPT is not without limitations. Challenges such as handling library version conflicts and managing complex tasks highlight the need for human oversight. Nevertheless, its ability to accelerate prototyping, enhance productivity, and generate creative solutions far outweighs its current shortcomings. By experimenting with use cases like dynamic prompt generation, test case creation, and language translation, developers can unlock AI's potential to augment their day-to-day operations. Furthermore, large scale usage of these tools will not only benefit their user but also their developers – supporting the accelerated development and enhancement of even better tools.

Looking ahead, as AI and NLP technologies continue to evolve further and further, support tools like ChatGPT are meant to play an increasingly more important and integral role in the field of modern software development. To fully realize these benefits, developers must embrace a mindset of continuous learning and innovation. By combining the power of AI with human ingenuity, we can navigate the challenges and opportunities of this new

technological frontier, shaping a real future in which the software development and code-generation are concomitantly faster, smarter, more accessible and permanently improving.

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