CREATING A HUMAN-FOCUSED FUTURE

EDITORS:
SERRA ÇELİK, SEVİNÇ GÜLSEÇEN, MELTEM ERYILMAZ

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Creating A Human-Focused Future

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PREFACE

When we first conceived the theme of this book, GPT-based AI systems hadn't yet taken over the world. Now, it seems we're practically incapable of breathing without AI tools. Whether you're a student, an academic, a software developer, or a communicator, regardless of the sector you work in, AI tools have become an integral part of our lives. This book also focuses on data-driven, or rather, AI-based, studies in various fields. In short, the focus is on studies that can be considered a starting point in the rapidly evolving AI universe. We hope you find our book, which also features industry applications, helpful.

Enjoy reading!

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Chapter 1

The Era of Large Language Models

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Abstract

In recent years, the fields of artificial intelligence (AI) and natural language processing (NLP) have undergone a significant transformation with the rise of large language models (LLMs). AI was first defined as an academic discipline in 1956 and has since evolved from rule-based systems to machine learning and deep learning. Today, LLMs are capable of understanding complex linguistic relationships by leveraging deep learning techniques on massive datasets, successfully performing tasks such as text generation, translation, and summarization. The core functioning of LLMs involves data collection, preprocessing, modeling, evaluation, and fine-tuning. These models are typically built using Transformer architecture and, due to their vast number of parameters, enable them to better grasp the context of language. LLMs are used not only in textual applications but also across various domains such as healthcare, law, and software development. However, they also face ethical challenges, including hallucination, lack of reasoning, and biases. In the future, more advanced techniques and approaches will need to be developed to overcome these challenges.

Keywords Large language models · natural language processing · artificial intelligence

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Introduction

With its rapid advancements in recent years, artificial intelligence (AI) has demonstrated its impact in nearly every aspect of life. Particularly in the past few years, it has become strikingly clear that there is hardly any field where the term AI is not encountered. It would not be incorrect to say that, following periods when AI research was stalled –referred to as the "winter of AI"– a "spring of AI" is now underway. This renewed interest in AI is undoubtedly linked to rapid and transformative progress of large language models (LLMs) in the field of natural language processing (NLP). LLMs have enabled the completion of time-consuming tasks in a much shorter time and have contributed to unleashing human creativity by reducing workload. Although some argue that the "Information Age" has not yet fully arrived, it is safe to say we are currently in the era of large language models. Introduced by OpenAI in 2022 as a chatbot, ChatGPT has made LLMs an indispensable part of everyday life due to its ease of use. In this context, this book chapter first provides definitions of artificial intelligence and natural language processing followed by an explanation of large language models. To understand the current significance of LLMs, it is essential to first explore the historical roots and foundational definitions of artificial intelligence and natural language processing.

Artificial intelligence was first defined as an academic discipline in 1956 at the Dartmouth Conference by John McCarthy, Marvin L. Minsky, Nathaniel Rochester, and Claude E. Shannon. It was conceived as the ability of a computer or a computer-controlled machine to perform tasks related to high-level cognitive processes such as reasoning, interpretation, generalization, and learning from past experiences –traits that are generally assumed to be unique to humans (Nabiyev, 2016). Researchers proposed that *"any aspect of learning or intelligence could, in principle, be so precisely described that a machine could be made to simulate it".* McCarthy and colleagues defined the aim of AI as *investigating how machines could use language, form abstractions and concepts, solve problems considered uniquely human, and improve themselves.* In other words, AI was conceived as the science and engineering of creating intelligent machines capable of achieving goals like humans. During its early years, AI systems mainly relied on rule-based approaches to execute specific tasks (McCarthy et al., 1955).

These early systems operated within predefined sets of rules and logical structures, enabling them to solve specific problems. For instance, one of the early AI applications, a chatbot named Eliza, could interact with users based on preset linguistic patterns (Weizenbaum, 1966). However, such systems lacked flexibility and were limited to narrowly defined scenarios. A major transformation occurred in the 1980s and 1990s when attention shifted toward machine learning and deep learning. Unlike rule-based systems, machine learning enabled computers to learn from data and make decisions based on experience. Deep learning, which implements this learning and decision-making process through multi-layered (deep) neural networks, further allowed AI to move beyond rigid rules and learn from information derived directly from data.

Claude Shannon, one of the researchers remembered from the original AI-defining team at the 1956 Dartmouth Conference, colloborated with Warren Weaver –one of the most influential scientists of the 20th century– while developing information theory seven years before the Dartmouth Conference. While contributing to Shannon's work on information theory, Weaver also conducted research on the mathematical modeling of language. In his 1952 memorandum titled *Translation*, he laid the groundwork for machine translation (Weaver, 1952). Weaver believed that, due to structural similarities across languages, it would be possible to develop language models enabling automatic translation between languages using computers. His vision sparked foundational research across artificial intelligence, natural language processing, and computer science. When the calendars showed 1954, this vision had materialized into action. A headline in the *New York Times* read: "*Russian is turned into English by a fast electronic translator*," marking a breakthrough moment in machine translation history. That same

year, IBM and Georgetown University collaborated on a machine translation experiment using a limited vocabulary of 250 words and basic grammar rules. Conducted at IBM's New York headquarters, the demonstration was celebrated in the media with headlines such as "It may be the result of centuries of scientists search for a *'mechanical translator'*,", "Electronic brain translates Russian,", "Two-language machine,", "Robot brain turns Russian into King's English," and "Polyglot brainchild" (Hutchins, 2004). While early efforts in machine translation laid the groundwork, the true transformation in language modeling came with the adoption of neural networks and deep learning techniques.

Language modeling, like artificial neural networks, has roots going back to the 1950s. At its core, language modeling is the task of predicting the next word in a sequence based on preceding words. This probabilistic approach was first outlined by Shannon in his foundational work on information theory (Shannon, 1948). Early language models, such as n-gram models, relied on simple probabilities between sequential words and were constrained by their limited context, resulting in relatively low prediction accuracy (Chen & Goodman, 1996). In contrast, modern language models are trained on massive datasets using deep learning algorithms, enabling them to analyze linguistic context and word relationships at a much deeper level and generate more meaningful, coherent predictions (Goldberg, 2017). With the development of deep learning-based models, approaches such as Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM) have made significant strides in capturing long-range dependencies within text. More significantly, Transformer-based models revolutionized the NLP field and laid the foundation for the rise of large language models (Vaswani et al., 2017).

Rachka (2024) states that artificial intelligence encompasses subfields such as machine learning and deep learning. In this context, deep learning is defined as a type of machine learning that utilizes multi-layered artificial neural networks. Machine learning, more broadly, involves the development of algorithms that can learn from data and make predictions or decisions based on that data. Deep learning, a subset of machine learning, focuses on using deep neural networks –networks with three or more layers—to model complex patterns and abstractions on data. Natural language models, then, are an application of deep learning techniques aimed at understanding and generating human language (Rachka, 2024, pp. 7–9).

Khurana and colleagues (2023) summarize some of the natural language processing tasks as follows:

- *Automatic Summarization*: Generating summaries of texts along with their detailed content,
- *Co-Reference Resolution*: Identifying all expressions in a text that refer to the same entity,
- *Discourse Analysis*: Examining text in relation to its social context,
- *Machine Translation*: Automatically translating text from one language to another,
- *Morphological Segmentation:* Segmenting words into morphemes, the smallest meaning-bearing units,
- *Named Entity Recognition*: Identifying and classifying names of entities within text,
- *Optical Character Recognition*: Converting printed or handwritten text into machine-readable form,
- *Part of Speech Tagging*: Identifying the grammatical category of each word in a sentence.

Large Language Models

Large Language Models are artificial intelligence models that apply natural language processing methods to vast datasets using deep learning techniques. The application of deep learning in natural language processing relies on neural network architectures specifically designed for understanding and

generating language. These neural networks are trained on extensive textual corpora to comprehend patterns and relationships within language (LeCun et al., 2025).

LLMs are specifically designed to understand and generate human language and are typically —though not always—based on Transformer architecture (Ozdemir, 2023, p. 31). Currently, generative artificial intelligence used for text-based tasks is predominantly focused on the development of large language models (Foster, 2023, p. 396). In other words, LLMs are models built upon deep neural architectures and are commonly trained on extensive text corpora through the task of predicting words in context. The term "large" in language models refers both to the number of parameters within the model and to the size of the training data (Mahowald et al., 2024).

Transformer-based LLMs contain hundreds of billions of parameters, enabling them to model the intricate dependencies and contextual nuances of language with greater depth. As a result, these models are capable of generating more fluent and contextually accurate translations. Moreover, multilingual LLMs are capable of translating across multiple language pairs using a single unified system. Such developments have significantly advanced machine translation, moving it beyond mere word substitution to include deeper semantic and contextual understanding-ultimately paving the way for the modern evolution of large language models (Devlin et al., 2018; Vaswani et al., 2017).

Definition, Development, and Basic Working Principles of LLMs

The basic principles of Large Language Models are data collection, preprocessing, modeling, evaluation, fine-tuning, and training. In the data collection phase, a large amount of data is gathered for training the model (Peter et al., 2018). These data can be obtained from articles, books, the internet, and various other sources. For instance, large-scale datasets compiled from texts such as Wikipedia, BookCorpus, Common Crawl, and various news websites play a critical role in enhancing the language capabilities of the models (Brown, 2020). The diversity of these data sources helps improve both general linguistic competence and performance in specific tasks. In the preprocessing phase, the collected data are prepared for the modeling process. This stage includes typical natural language processing operations such as tokenization, capitalization, and the removal of unnecessary words or symbols (Mikolov et al., 2013). In the modeling phase, models are trained using neural networks and machine learning techniques to help the model learn grammar rules, word associations, and meanings from the data (Bahdanau et al., 2014). Through this training, models gain the ability to comprehend input text and generate new outputs. In the evaluation phase, the models' performance is assessed using test datasets. This stage is crucial for understanding how well models *"understand"* and predict accurate outputs. It also helps identify the models' weaknesses and provides insights for improvement. In the fine-tuning and training phase, feedback obtained from evaluation process is used to tune and train the models' parameters and improve their performance. This phase further enhances the models' understanding of language and their predictive abilities.

Language models follow a structure and training process based on probabilistic machine learning principles. The basic steps followed by LLMs in natural language generation can be summarized as follows:

1. Probabilistic Machine Learning: A mathematical model is developed to make predictions that best represent the distribution of natural language data with the highest probability.
2. Transformers and Attention Mechanisms: Modern language models utilize Transformer-based deep learning architectures to learn complex relationships between words. This structure converts textual input into numerical representations based on relative importance.
3. Pre-training and Fine-tuning: Models are fine-tuned through domain-specific training and the adjustment of hyperparameters. In this process, the outputs are also reviewed to minimize bias.

4. Continuous Evaluation: Models are continuously assessed through various methods, including prediction accuracy (perplexity score), comparison with human-written text (BLEU score), and human expert judgments.

From a historical perspective, natural language processing has evolved from statistical language models to neural language models, followed by the development of pre-trained language models, and, ultimately, large language models (Naveed et al., 2023). More recently, Multimodal Large Language Models (MLLMs) have emerged, capable of processing data from different modalities. MLLMs combine NLP capabilities with other forms of input such as images, audio, and video. In other words, while classical AI models are limited to processing only textual information, MLLMs have the ability to integrate and interpret multiple data types –including text, images, sound, and video. Imagine an AI system capable of going beyond mere reading and writing –one that receives a product image along with an audio recording describing an issue. A multimodal large language model (MLLM) can process both the visual and auditory inputs simultaneously, integrating them to form a holistic understanding. This comprehensive interpretation allows the model to deliver more accurate and insightful responses by taking all available data into account. Among the most well-known MLLMs are GPT-4V, Macaw LLM, ImageBind, LLaVA: Large Language and Vision Assistant, NExT-GPT, and CogVLM.

Popular Language Models

Today, the most widely used language models in the field of NLP are referred to as LLMs, most of which are based on the Transformer architecture. Among these models, OpenAI's GPT *(Generative Pre-trained Transformer)* series, Google's BERT (*Bidirectional Encoder Representations from Transformers*), and Facebook's RoBERTa (*A Robustly Optimized BERT Pretraining Approach*) are among the most prominent examples (Devlin et al., 2019; Liu, 2019; Radford et al., 2019). These models differ in terms of application areas, data processing methods, and performance requirements. For example, the GPT series excels at tasks such as text generation and completion. GPT is designed as a unidirectional language model and has been trained on a vast amount of online text data. In contrast, BERT and its derivatives utilize a bidirectional modeling approach, analyzing sentence context in both directions to deliver more accurate semantic representations –an advantage especially useful in tasks such as sentiment analysis and text classification (Devlin et al., 2019). RoBERTa, developed by Facebook AI in 2019, is an optimized variant of BERT, retrained on larger datasets and adjusted for efficiency, achieving higher accuracy rates (Liu, 2019). Google's BERT, OpenAI's GPT, and Google's T5 are among the most popular LLMs. Although they all rely on the Transformer architecture, they differ in structural design. Additionally, models such as RoBERTa, BART, and ELECTRA are also among the large language models built on the Transformer framework (Ozdemir, 2023, p. 55).

DALL·E, also developed by OpenAI, is a model designed to generate images from textual descriptions. It uses Transformer-based architecture capable of producing high-quality visuals based on user input. Drawing on its understanding of visual concepts and their textual representations, DALL·E is able to create novel images that do not exist in the real world. By combining diverse elements into coherent compositions, it demonstrates advanced capabilities in visual synthesis. CLIP (*Contrastive Language–Image Pre-training*) is another model developed by OpenAI that serves as a bridge between text and images. It can understand and classify images based on textual prompts. Trained on a large dataset of images and corresponding text descriptions, CLIP is capable of performing tasks such as zero-shot image classification. This functionality makes it particularly valuable for applications requiring broad contextual image recognition or interpretation.

LaMDA *(Language Models for Dialog Applications)* is a speech-based AI model developed by Google and focuses on open-domain dialogue. Whereas traditional models rely on specific data sets, LaMDA

is pre-trained on a mixture of dialogue and web text to produce context-appropriate and expressive responses. It aims to improve the grounding of conversations by integrating external knowledge and reducing instances of "hallucination –producing logical but unrealistic information" (Thoppilan et al., 2022).

One of the most distinctive features of LLMs is their enormous scale. For example, GPT-3 contains over 175 billion parameters and was trained on approximately 570 GB of filtered text data. This immense scale enables the model to develop a broad and detailed understanding of language and context, but it also presents challenges related to computational resource demands and potential biases in the training data (Venkatasubramanian & Chakraborty, 2025). Since 2018, the number of parameters in each successive GPT model has increased in parallel with the size of its training dataset. From a performance perspective, this growth has contributed to making the models' outputs increasingly human-like (Venkatasubramanian & Chakraborty, 2025).

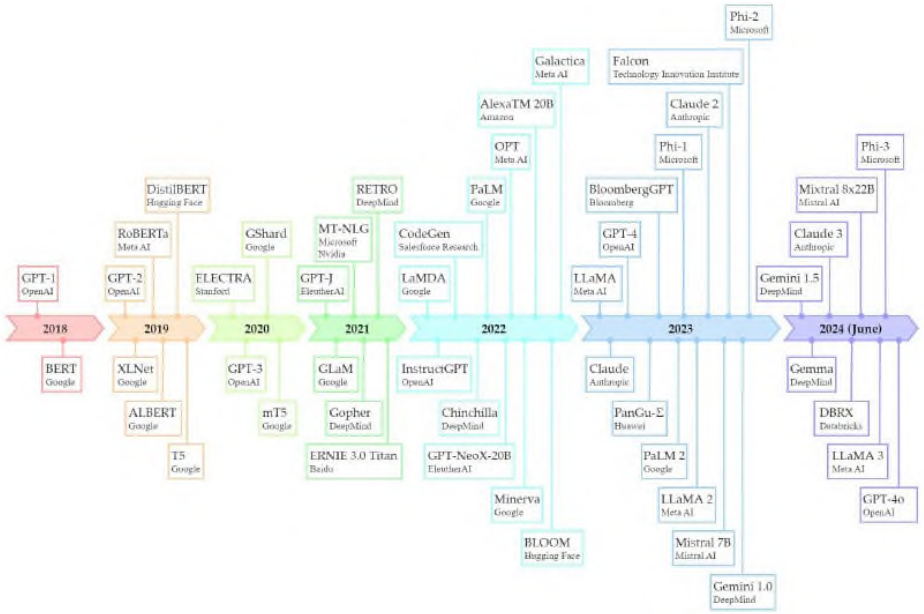
From an infrastructure perspective, training these large-scale models requires advanced hardware such as high-performance Graphics Processing Units (GPUs) and Tensor Processing Units (TPUs). NVIDIA GPUs are a popular choice for many language models due to their high data processing power and parallel computing capabilities (Shoeybi et al., 2019). Google's TPU infrastructure has been particularly favored for training models like BERT and similar models developed by Google in 2018, due to its high processing speed and efficiency. These infrastructures facilitate faster training and allow for the handling of larger datasets and greater parameter scales.

In addition, there are domain-specific LLMs trained in specialized subject areas. These models are designed to understand the specialized language and terminology used in fields such as biology or finance (Ozdemir, 2023, p. 58). For instance, LLMs adapted for bioinformatics purposes are widely used across various applications within the field. Such applications may include protein structure prediction, biological sequence analysis, drug discovery, gene expression analysis, and biological pathway analysis (see Sarumi & Heider, 2024 for more details).

New and more advanced versions of the language models summarized above are being introduced to users on an ongoing basis. In addition to the models previously mentioned, several high-performance LLMs have emerged. Notably, GPT-4o, released by OpenAI in May 2024, supports multimodal input including voice and video, enables more natural human interaction, and can analyze and comment on photos and screenshots. Other prominent models include Copilot, Microsoft's chat and search assistant; Bard/Gemini, part of the MLLM family developed by Google DeepMind; LLaMA (*Large Language Model Meta AI*), introduced by Meta in 2023; and Claude, developed by Anthropic, which is accessible via web, mobile, and API. A major breakthrough, however, has been achieved by the open-source large language model DeepSeek-R1. Released in January 2025, this model has demonstrated significant advancements in solving complex problems, self-verification, and chain-of-thought reasoning. Figure 1 presents a chronological overview of LLMs as summarized by Hang et al. (2024).

Figure 1

The timeline of the development of LLMs from 2018 to 2024 (June). Hang et al. (2024)



Common uses of LLMs

LLMs are widely used for tasks that involve text generation, translation, question answering, summarization, and coding. When trained specifically for a given domain, these models can deliver highly effective results. In essence, they reduce the workload involved in writing from scratch and assist users in transitioning from text creation to tasks such as editing and personalization (Brown, 2020; Radford et al., 2018). Through a method known as Knowledge-Intensive NLP, LLMs can serve as knowledge bases that respond to user inquiries (Jacobs, 1987). They are also effective in text classification, making them suitable for applications like sentiment analysis (Devlin et al., 2018). Companies can use LLMs to analyze customer feedback, assess product or service performance, and implement necessary updates. In the medical and healthcare domains, LLMs can support physicians by analyzing medical records, diagnosing diseases, and assisting in personalized treatment planning (Murff et al., 2011). For instance, Google's Med-PaLM has been developed to enhance physicians' understanding of medical archives and accelerate clinical decision-making processes (Singhal et al., 2022). In legal contexts, LLMs can perform well in reviewing contracts and legal documents. Since they are proficient in many programming languages, LLMs can also ease the burden of routine coding tasks, allowing developers to focus on higher-level functions. Across industries, these models have the potential to replace repetitive textual tasks and shift human workers into more strategic, decision-making roles. With continued development through user prompts, LLMs can now handle increasingly complex queries and even infer user intent (Brown, 2020).

In a study examining the clinical applications of LLMs, Le and colleagues (2024) explored their use in vascular surgery by processing outpatient referral requests. The researchers created 25 fictional referral requests based on commonly observed scenarios in vascular outpatient settings. Five expert surgeons and four large language models (GPT-3.5, GPT-4, Bard, and Falcon 40B) were asked to determine, for each request, whether it indicated an urgent condition requiring intervention within one hour and what the

most appropriate next step would be –whether consultation, use of an additional imaging technique, or immediate surgery. The accuracy rates for identifying urgent cases were 88% for GPT-3.5, 100% for GPT-4, 76% for Falcon 40B, and 88% for Bard. While the models performed well in identifying emergencies – GPT-4 agreeing with the surgeons in all cases– they showed limitations when tasked with more complex responsibilities such as recommending specific treatment plans (Le et al., 2024).

Researchers evaluating how LLMs like ChatGPT might contribute to plant science found that LLM-generated research questions occasionally highlighted perspectives that human scientists had overlooked. However, researchers also noted that questions formulated by experts often contained creative elements that could not be replicated by models trained solely in existing data. These findings suggest that LLMs have the potential to complement the strengths of scientists, streamline and accelerate the research process, and expand the horizons of scientific inquiry (Agathokleous et al., 2024). Although the study focused on plant science, its implications may be extended to other fields, reinforcing the idea that LLMs can serve as valuable support tools in scientific research –provided they are used with appropriate caution.

Ethical Considerations

Bzdok et al. (2024) have outlined several limitations associated with the application of LLMs. The first of these is hallucination, which refer to instances where LLMs generate information or text that is disconnected from reality or context. These models are capable of producing fabricated or incorrect content that can be difficult to distinguish from accurate information. A related limitation is the lack of reasoning ability. LLMs often struggle to comprehend and respond to new situations that are not present in their training data. Another limitation is the dependence on large-scale data. LLMs require vast amounts of input data, much of which is sourced from the internet. In addition, the application of LLMs demands substantial computational power, storage capacity, and energy consumption. One of the most significant limitations involves biases and ethical concerns. LLMs tend to inherit biases present in their training datasets. Furthermore, determining whether a piece of text has been generated by an LLM is often challenging. It is also difficult for both users and developers to understand or explain why a model has produced a particular response, which raises concerns about transparency and explainability. Finally, there is an observed diminishing return in scaling. Increasing data and computational resources no longer yields proportionally beneficial improvements. As a result, alternative strategies are needed to advance LLM capabilities to the next level (Bzdok et al., 2024).

In May 2024, The Council of Higher Education in Türkiye (YÖK) published the Ethical Guidelines on the Use of Generative Artificial Intelligence in Scientific Research and Publication Activities in Higher Education Institutions. It emphasized that scientific research and publication gain value through original ideas and authentic findings. In this context, it is stated that the use and purpose of generative AI should be limited so as not to cover higher-level stages requiring advanced knowledge, experience, and expertise –such as hypothesis development, discussion, interpretation, and application. The fundamental ethical values determined by Higher Education Institutions regarding the use of generative AI in scientific contexts include: transparency, honesty, diligence, fairness and respect, protection of privacy and confidentiality, accountability and responsibility, and contribution to an ethical setting.

The core ethical principles established by Higher Education Institutions for the use of generative AI in scientific research emphasize transparency, integrity, diligence, fairness and respect, protection of privacy and confidentiality, accountability and responsibility, and providing an ethical research environment.

Conclusion

Despite their impressive performance, LLMs can also produce a significant number of erroneous outputs. In the future, improvements in handling errors and enhancements in processing audio and video prompts may allow LLMs to acquire more human-like intuitive capabilities. Just as a human can detect danger in an environment simply by hearing certain sounds, LLMs could also derive deeper meaning when supported by audio inputs.

According to Venkatasubramanian and Chakraborty (2025), although LLMs appear to possess a broad range of knowledge across many subjects, they often fail to develop a deep understanding of that knowledge. While they may *"know"* many things on the surface, they do not grasp core principles in a meaningful way. Because LLMs are data-driven systems, they cannot truly comprehend or analyze information. As such, it is difficult for them to capture the concept of meaning in a holistic sense. For example, although an autonomous vehicle may navigate through traffic impressively, it does not understand physical principles like mass, momentum, acceleration, force, or Newton's laws in the way humans do. Its behavior resembles that of a cheetah chasing an antelope –both may execute the dynamics of a chase with mastery, but it cannot be claimed that they *"understand"* the physical mechanisms underlying this process. Current AI systems, at best, demonstrate a level of competence in their tasks similar to that of animals, but they remain far from achieving the deep understanding possessed by humans. This gap represents a serious limitation (Venkatasubramanian & Chakraborty, 2025).

In a study conducted by Loconte et al. (2024), Italian neuropsychological tests –typically used to assess prefrontal functions in humans– were administered to GPT-3.5, GPT-4, Claude2, and LLaMA2 to evaluate the intelligence level of large language models. When compared to human performance, GPT-3.5's results appeared inconsistent; while it performed well above average on some tasks, but it performed low or insufficient on other tasks. The model struggled particularly with planning tasks, recognizing semantic absurdities, and understanding others' intentions and mental states. Similarly, Claude2 exhibited a performance profile close to GPT-3.5, whereas LLaMA2 performed poorly across nearly all tests. These inconsistencies suggest that current LLMs are not yet capable of fully mimicking human cognitive functioning. The only exception was GPT-4, which performed within the normative range for all tasks –with the exception of planning abilities (Loconte et al., 2024). Therefore, while LLMs continue to evolve and expand their capabilities, a balanced approach that combines technological innovation with ethical responsibility will be essential to ensure their beneficial integration into society.

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Chapter 2

A Holistic Overview of the Interaction Between Artificial Intelligence and Cinema

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Abstract

This study explores the multifaceted and rapidly evolving relationship between artificial intelligence (AI) and cinema, situating AI not only as a subject of narrative within films but also as an active agent in the production, distribution, and reception of cinematic content. While AI has historically occupied a symbolic and speculative role in science fiction cinema—often depicted through utopian or dystopian imaginaries—its contemporary applications are reshaping the foundational processes of filmmaking and film studies. The integration of AI into the cinematic workflow—from scriptwriting and cinematography to editing, marketing, and exhibition—demonstrates its increasing relevance as both a creative collaborator and a technological infrastructure.

The study further examines how algorithmic systems, recommendation engines, and AI-driven platforms are transforming audience behavior and market segmentation, raising critical concerns about echo chambers, cultural homogenization, and the ethical implications of data-driven personalization. Drawing from theoretical frameworks by scholars such as Lev Manovich, Walter Benjamin, and Henry Jenkins, the research also interrogates the philosophical dimensions of creativity, authorship, and artistic agency in an era where generative AI tools such as DALL·E or Sora allow users to materialize their ideas without traditional artistic training.

Through a descriptive analytical method, the paper provides a holistic perspective on the role of AI in contemporary cinema and related visual cultures. Key areas of inquiry include AI's influence on the material processes of film production, its epistemological and methodological implications for film studies, and the shifting dynamics of art, authorship, and audience in the post-digital age. Ultimately, this study argues for a multidimensional approach that addresses not only the technological and aesthetic transformations driven by AI, but also their broader sociocultural and ethical consequences.

Keywords AI (Artificial Intelligence) · cinema studies · creativity · algorithmic culture · digital aesthetics

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Introduction

Artificial Intelligence (AI) has significantly influenced fields such as computer science, information technology, and cognitive studies, while simultaneously transforming scientific research, industry practices, and social life. In its early phases, the relationship between cinema and AI was largely confined to the domain of science fiction. More recently, however, the role of AI as a creative agent has become a central topic of inquiry.

From a broader perspective, AI has impacted cinema in multiple ways—from its initial emergence as an intellectual concept to its more recent transformation of production tools and creative processes. These influences are neither unidirectional nor strictly linear, and they do not follow a clear chronological or categorical order. Nevertheless, they can be analyzed under distinct subheadings within film and audience studies, including production, distribution, exhibition, display, and promotion (Parlayandemir, 2022).

Throughout the history of cinema, artificial intelligence has both shaped and been shaped by the collective consciousness of society and individuals—most notably through its recurring presence in science fiction as a theme rooted in utopian and, more often, dystopian imaginaries.

From a production-oriented perspective, AI can serve as a sectoral guide for understanding its current and potential applications in screenwriting, cinematography, and post-production processes (Babacan, 2024; Oğuzcan, 2025; Zengin, 2020). In this context, AI is not only a subject of cinematic narrative but also an active participant in the material processes of filmmaking.

Beyond these production-related issues, new media in general—and AI in particular—have deeply influenced cinema and transformed video art, which, like cinema, is ontologically dependent on technology. Although the historical trajectory of AI's impact on video art falls outside the scope of this study, recent debates surrounding the work of Refik Anadol bring to the fore questions about the dehumanization of art and the broader implications of digital colonization. These critiques, as Artun (2021) notes, invite reflection on how AI may alter art–society relations in the long term, extending beyond the boundaries of cinematic production.

In the context of distribution and display, several questions arise concerning whether AI produces effects similar to those associated with earlier digitalization processes. While algorithms may enhance the speed and precision with which content reaches its target audience—potentially seen as a positive development in terms of publicity—there are also cases that complicate this view. One such example is the censorship of the promotional poster for Pedro Almodóvar's *Madres Paralelas* by Instagram's algorithm. Following public backlash, Instagram issued an apology and ultimately allowed the poster to remain in circulation (Ramachandran, 2021). This incident serves as a notable case study in the discussion on algorithmic moderation and cultural expression.

Additionally, the role of AI in shaping audience experience through recommendation systems on online streaming platforms remains a contested issue. While such algorithms facilitate decision-making by tailoring content to individual preferences (Zengin, 2021), they also risk creating echo chambers —narrowing the cinematic experience and fragmenting public discourse. This concern is particularly relevant in light of the ongoing transformation of cinema audiences from a collective public into segmented user groups, driven by both the affordances of digital platforms and the global shifts brought about by the post-pandemic context.

One of the central issues addressed in this study is the functional role of artificial intelligence in the field of cinema studies. The potential of AI to shape the future of film scholarship—particularly in areas such as sample selection and methodological design—necessitates critical engagement with

debates surrounding machine learning and data neutrality. The transformative impact of AI extends beyond academic research to encompass the teaching and practice of filmmaking itself.

This study, employing a descriptive analysis approach, aims to offer a holistic perspective on these interrelated discussions. Topics explored include the integration of AI into film and social science research, the implications of machine learning for critical methodology, questions of data neutrality, and the future of cinema education in the age of artificial intelligence.

Where Do We Learn the AI: Science Fiction Cinema and AI

As one of the most influential art forms of the 20th century, cinema has functioned not only as a means of mass communication but also as a tool for interpreting and making sense of the world (Parlayandemir, 2022b, p. 10). These cinematic insights intersect with various domains within cultural studies and the social sciences—such as gender and orientalism-which, although indirectly related through the biases embedded in artificial intelligence (AI), nonetheless inform our analysis. More directly, however, cinema's longstanding relationship with science and AI provides a critical foundation for this study.

Until recently, when AI began to significantly impact everyday life, it primarily remained within the purview of researchers. Nevertheless, AI has long captivated the cinematic imagination. In early cinema, its representation closely mirrored that in literature: AI entities often rebelled against their creators and became existential threats, as famously exemplified by the story of *Frankenstein*. These portrayals metaphorically align with the concept of "otherness," serving as cultural reflections of human anxieties (Asukas, 2022; Işık, 2024).

Conversely, some narratives adopt a transhumanist perspective, encouraging audiences to empathize with AI itself. Films such as *A.I. Artificial Intelligence* and *Ex Machina* allow viewers to identify with artificial beings, thereby challenging traditional subject–object boundaries (Yılmaz & Turan, 2018). In general, cinematic depictions of AI tend to mirror the broader representation of "the Other" in science fiction cinema (Parlayandemir & Oğuzcan, 2023).

Although the concept of artificial beings can be traced back to antiquity (Babacan, 2024), the history of AI representation in cinema is often anchored in two distinct early examples. *L'uomo Meccanico (The Mechanical Man*), an Italian silent film released in 1921, is frequently cited as one of the first cinematic portrayals of an autonomous machine (Çoker, 2016, p. 24; Hasdemir & Berk, 2024, p. 5; Yılmaz & Turan, 2018, p. 285).

From the 1950s and 1960s onward, robots, autonomous machines, and cyborgs became central figures in mainstream science fiction cinema (Murphy, 2024). Cult classics such as Kubrick's *2001: A Space Odyssey* and Spielberg's *A.I.* explore not only human empathy toward machines but also machines' capacity to evoke emotional responses. *Ex Machina* (Dir. Garland, 2014), in particular, adopts an AI-centered gaze, culminating in a narrative catharsis that punishes unethical human behavior.

Moreover, as Çanğa Bayer (2021) notes, the relationship between cinema and AI is dialectical: while audiences learn about AI through films, AI systems themselves can also learn from cinematic representations. This reciprocal interaction positions cinema not only as a reflective medium but also as a dataset—a cultural resource through which AI models are trained, shaped, and socially informed.

How Can AI Affect the Cinema Industry?

AI technologies are increasingly being integrated across all stages of film production, generating a significant transformation within the cinema industry (Parlayandemir, 2022).

In the pre-production phase, AI-powered tools assist in optimizing budgets, planning shooting schedules, and organizing production crews more efficiently (Türten, 2024). During scriptwriting, natural language processing (NLP) algorithms are used to analyze narrative structures and even generate original screenplays. A notable example is the 2016 film *Sunspring*, whose script was written entirely by an AI system named Benjamin (Anadolu, 2019; Parikh, 2019). Furthermore, as illustrated by the case of Netflix's *House of Cards*, audience data analytics supported by AI were used during development to guide creative decisions such as casting and narrative direction (Carr, 2013).

In production design, computer vision techniques enable automated analysis of set aesthetics, costume choices, and spatial composition. AI-assisted cameras can adjust lighting and framing in real-time during shooting. In the field of music composition, AI algorithms are increasingly used to generate emotionally resonant scores that align with the tone and rhythm of individual scenes (Babacan, 2024, Türten, 2024; Zengin, 2020). Additionally, film fragments can also be generated using AI, demonstrating the expanding creative capabilities of artificial intelligence in cinematic production (Cevher & Aydın, 2020).

In post-production, AI enhances editing and visual effects workflows by introducing automation, which significantly reduces both time and costs. A widely recognized example is the use of Adobe Sensei within Adobe Premiere Pro, showcasing how AI has been adopted by the industry for professional editing tasks. Dubbing is also undergoing transformation through real-time AI-based language translation and voice conversion technologies. Additionally, in a recent debate surrounding the film The Brutalist, AI was reportedly used to enhance the articulation of Oscar-winning lead actor Adrien Brody—a development that raises new questions about the role of AI in performance and acting (Murphy, 2025).

In distribution and promotion, AI facilitates audience analysis and personalized marketing strategies, significantly increasing the reach and impact of films (Zengin, 2021). Looking back to the origins of cinema, it is evident that technological innovation—driven by inventors and engineers—was foundational to the emergence of film as an art form. Today, with the integration of AI into the film industry, this historical dynamic is being reactivated. Software companies such as ScriptBook, Cinelytic, Largo AI, and others have gained prominent positions in the cinematic workflow.

Especially in the domains of distribution and exhibition, companies developing or implementing AI-based tools have come to occupy a critical role. Tools such as Cinelytic, Largo AI, ScriptBook, Gray Matter LLC, Synchtank, StoryFit, Papercup, Unbabel AI, and Respeecher are frequently utilized in distribution processes. Meanwhile, platforms such as Deluxe Media (Apptek), Movio, FilmTrack, MovieSaints, 3XM Technologies, Merlin, Pilot.ly, Airship, and Valossa Labs OY support AI-driven innovations in exhibition (Türten, 2024b, p. 384).

However, the integration of AI into cinema also raises several critical concerns. These include potential job displacement, ethical dilemmas, biased representations that reinforce stereotypes, algorithm-induced echo chambers, and the blurring of reality through hyperrealistic imagery (Oğuzcan, 2025). As Zengin (2020) emphasizes, AI's role in cinema must be examined not only from a technological standpoint but also through ethical, aesthetic, and sociocultural lenses.

As in many other sectors-particularly within the creative industries—the threat of unemployment has become central to these debates. In the United States, for instance, a major strike organized by SAG-AFTRA in 2023 sought to protect the rights of workers against the industry's growing reliance on AI-driven production models (SAG-AFTRA, 2025).

Philosophic Discussion: Will We Still Call It Art Even If It's Not Produced by an Artist?

The relationship between AI and art constitutes a significant area of inquiry within both disciplines. Scholars such as Lev Manovich have raised foundational questions that continue to shape contemporary debates: What do we mean by creativity? Is it a fixed and universal concept, or does it evolve according to historical conditions, cultural contexts, and technological developments? Manovich (2022) also critiques the contemporary obsession with creativity, questioning why it holds such a central position in our cultural imagination.

In this context, Muratoğlu-Pehlivan and Türkgeldi (2020, p. 2649) discuss the shifting roles of both the author and the audience in the postmodern era under the influence of AI and emphasize that "where creativity lies on the blurring border between human intelligence and AI becomes an important question."

At the same time, reflections on creativity must contend with critical theories that problematize the notion of artistic originality in modernity. Walter Benjamin (2008), in his seminal essay *The Work of Art in the Age of Mechanical Reproduction*, interrogates the aura and authenticity of reproduced artworks. Similarly, Theodor Adorno (1991) positions mainstream cinema within the framework of the "culture industry," arguing that it relies on standardized codes and formulas that limit the potential for genuine creative expression. Within such frameworks, one might ask whether true creativity is attainable in industrial cinema—or even in art cinema, which often develops its own recognizable conventions.

As Henry Jenkins (2006) argues, emerging paradigms such as transmedia storytelling, participatory culture, and prosumer societies further complicate traditional understandings of creativity. In alignment with these paradigms, generative AI tools like DALL·E or Sora enable end-users to visualize and materialize their own ideas. This development democratizes the creative process and challenges conventional notions of authorship, originality, and artistic agency.

In this regard, Daly's (2010, p. 81-82) concept of Cinema 3.0 becomes particularly relevant: it "might be a cinema of the user, as the time-image gives way to the interactive-image." This perspective reflects a broader shift in which the spectator is no longer a passive receiver of meaning, but an active participant in shaping the cinematic experience—particularly in the context of AI-supported content generation and interactive narratives.

However, these developments also raise new concerns. If creative outputs are generated through data sets and algorithms trained within the logic of the culture industry, then even the most personalized AI-generated content may reflect broader systemic patterns. In this context, the neutrality of data and algorithms becomes a central philosophical concern. Can we still call it "art" if the creative process is shaped not by the intentionality of an individual artist, but by machine-learning systems embedded within industrial and cultural codes?

Scientific Discussion: How will AI Affect the Film Studies?

AI has influenced science from two major perspectives. First, it emerged as a prominent topic within disciplines such as computer science and mathematics. Over time, however, it has also become a subject of inquiry in the social sciences and humanities, where attention has shifted toward its societal implications and its potential to shape the future of various fields, including philosophy, economics, and sociology (Bircan & Salah, 2022).

From another perspective, AI has transformed the way scientific research is conducted. The rise of data-driven science has introduced a paradigm often regarded as more objective, as it is believed

to offer a closer approximation to truth (Huang, 2022). Nonetheless, this shift has raised significant concerns regarding algorithmic bias, embedded prejudices, and the possibility of data manipulation (Miller, 2019).

In light of both the opportunities and risks AI presents, its potential applications in film studies can be explored through both quantitative and qualitative methodologies. In quantitative research, AI facilitates the analysis of large datasets in considerably less time, increasing the efficiency and scope of the study. However, the more profound transformation is likely to occur within qualitative approaches. AI also creates a possibility with studying larger sample sets for qualitative analysis. An example of this case is Refik Anadol's *Alkazar Dream* project (2022), which was exhibited at Hope Alkazar in Istanbul between May 29, 2022, and October 19, 2022. In this project, Anadol transformed approximately 150 films into datasets that could be analyzed using AI.

As Rose (2002, p. 30) suggests, film studies can be broadly categorized into three main areas of analysis: the "site of the image itself" (which encompasses all visual and auditory elements beyond the script and dialogue), the "site of production" (i.e., the film industry), and the "site of audiencing" (the ways in which audiences engage with and interpret films). Integrating AI into these areas offers new possibilities for both methodological innovation and critical engagement.

For instance, in the analysis of the image itself, tools such as natural language processing (NLP) and computer vision can be employed to interpret visual and auditory content at scale. Within the domain of film production, techniques like machine learning (ML) and data mining can be utilized to examine trends, workflows, and industrial structures. In audience studies, methods including NLP, data mining, ML, and even neuroscience-based approaches may offer new ways of understanding viewer engagement, interpretation, and emotional response.

Cinema Education and AI: How Can We Use AI in Filmmaking Education?

Not only the film industry and the academia but also educational approaches are being increasingly influenced by artificial intelligence (AI). Teaching with AI and teaching the AI are gaining importance. AI, in conjunction with virtual reality (VR) technologies, can be used to simulate film production environments, providing students with immersive and practical training experiences that enhance both technical skill development and creative experimentation. Furthermore, considering AI trend, filmmaking education is poised to undergo significant transformation through the integration of AI. Film students and scholars alike will need to acquire a solid understanding of AI in order to keep pace with the zeitgeist, as every dimension of film studies—from production to theory—is now subject to the influence of artificial intelligence. As Netflix CEO Ted Sarandos (2024) aptly stated, "AI won't replace writers or take your job—but the person who uses AI well might." But any speech does need to stop us thinking about neither unemployment risk and ethical concerns about the fact nor the potentials and essentiality of the fact.

In conclusion, the evolving interaction between artificial intelligence and cinema reveals both transformative potentials and critical challenges. As AI reshapes not only cinematic production, aesthetics, and education but also research methodologies in film studies, it demands deeper ethical, epistemological, and philosophical reflection. This multidimensional shift invites scholars, creators, and educators alike to reconsider traditional notions of creativity, authorship, audience, and scientific inquiry. Ultimately, cinema and AI are no longer separate domains but interwoven systems that mutually shape one another's development and future trajectories.

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Chapter 3

A Relocate Suggestion for PTT Centers Depends on Optimization Techniques

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Abstract

The Turkish Post and Telegraph Organization, commonly known as PTT is Türkiye's national postal service. In an optimization-related context, a postal and logistics provider can concentrate on reducing transportation costs through strategic optimization of its distribution network. Currently, the PTT network comprises 479 branches and 134 distribution centers. Our analysis investigates the alternative locations for the 134 centers using various optimization techniques. Heuristics and Mixed Integer Programming (MIP) are among the common approaches for binary variable p-median model commonly used in facility location optimization. Given the NP-hard nature of the p-median problem, researchers often advocate for the use of heuristics, particularly when addressing larger-scale instances.

Currently, there is no universal cutoff model size for choosing between heuristics (approximate methods) and exact solvers. In order to address this uncapacitated p-median model with 134 binary variables; we assess the feasibility and usability of the two approaches to the current size by implementing various Genetic Algorithm (GA) models, testing different GA parameters to evaluate their impact on model efficiency and we applied Mixed-Integer Programming (MIP) optimization using the GLPK solver.

The complexity of NP-hard problems grows exponentially but the study demonstrates that MIP methods remain effective for the current variable size and model structure. They provided the best solution with a fitness score of 90411.59 versus 154218.99 for the current network. The results underscore the significant impact of generation size on both runtime and solution quality in GA approaches, which provided also practical, near-optimal solutions within longer but still acceptable timeframes (fitness score: 95,349.7 in approximately 45 minutes). In conclusion, both strategies could aid PTT size postal and logistics provider in reducing expenses while enhancing service quality.

Keywords P-median problem · genetic algorithms · facility location optimization

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Introduction

Postal and logistics companies carefully balance customer satisfaction alongside financial profitability to promote long-term sustainability. In this optimization context, a postal and logistics provider can reduce transportation costs by using the most cost-effective paths for deliveries and a strategic optimization of its distribution network. Turkish Post and Telegraph Organization (PTT) is the national postal and telegraph directorate of Türkiye. PTT manages the transportation of goods across the country. PTT operates 479 branches in Istanbul, organized around 134 distribution centers. It is continuously evolving its network by strategically implementing new facilities. This study focuses on optimizing the PTT distribution network through an uncapacitated p-median model including 134 binary variables—representing the distribution centers in the network-and three linear constraints. Given its complexity, the model is classified as NP-hard (Mirchandani & Francis, 1990).

Heuristic approaches are often preferred in NP-hard optimization problems as they prioritize speed and approximation over absolute accuracy and completeness (Žerovnik, 2015). However, the selection of the right approach can depend on many factors such as the amount and nature of variables, the model sparcity and structure.

Genetic Algorithm (GA) is a specific heuristic optimization technique inspired by the principles of natural selection and genetic evolution. Developed in the 1970s based on the ideas of John H. Holland (Holland, 1992), GA has evolved into a widely used method for solving complex optimization problems (Oksuz et al., 2016). GA implementations leverage the genetic operators of selection, crossover, and mutation to iteratively improve potential solutions (Goldberg, 1989).

Aimed to suggest optimal locations for PTT Centers using optimization techniques, this study investigates also the impact of various GA parameters on the final result and assess the performance of heuristics and exact solution approaches for size of current problem. The Genetic Algorithm (GA) achieved a fitness score of 95,349.7, compared to 90,411.59 for the MIP solution, and 154,218.99 for the current situation. This study highlights the efficiency of optimization techniques in decision-making, particularly for designing new distribution networks, integrating new nodes into existing systems, or relocating current distribution centers.

Materials and Methods

Location and Distance Data

The data about geographical coordinates of the nodes (PTT branches), is available from the PTT's official website ("En Yakın PTT," n.d). The dataset provides also the status parameter indicating whether a node is a distribution center or not and additional informations such the name, and working time. This information was extracted in JSON format and converted into a "pandas DataFrame" for further processing in a Python environment (McKinney, 2010). A more realistic model could include parameters such as population density, traffic, etc; this project utilize simplified models based on the traveled distances.

The data cleaning process yields a tabular dataset containing 479 entries and 5 features: ID, Name, Latitude, Longitude, and Status column binary encoded to represent the status of each node (Table 1). Also, some example data has been given in Table 2.

Table 1
Data description

	Column	*Non-Null count*	*Dtype*
0	**ID**	479 non-null	Integer
1	**ADI (name)**	479 non-null	object
2	**LONG**	179 non-null	object
3	**LAT**	479 non-null	object
4	**CINS (type)**	479 non-null	object

Table 2
Subset of data

	ID	ADI (Name)	LONG	LAT
0	**4405**	HASTANE ŞUBESI	29,1072	40,96997
1	**2800**	100. YİL MAHALLESİ ŞUBESİ	28,85444	41,5938
2	**6334**	15 TEMMUZ ŞEHİTLER MERKEZİ	29,08064	41,02768
3	**5989**	15 TEMMUZ ŞEHİTLER KÖPRÜSÜ OTOYOL ACENTELİĞİ	29,04082	41,03854

Realistic travel costs estimations between each pair of branches and the shortest trajectory characteristics are obtained using the Mapbox Matrix tool, a routing and navigation platform provided by MapBox Inc ("Matrix API," n.d.). Table 3 represents a subset of the obtained distance matrix.

Table 3
Distance matrix

Node ID	0	1	2	3	4		474	475	476	477	478
0	0.0	2250.5	3306.9	1544.6	3036.6	...	1788.1	1500.5	1725.9	3038.2	830.3
1	2402.1	0.0	3460.7	3196.5	1811.7	...	2558.9	1413.6	1991.5	1350.1	1981.5
2	3486.7	3367.4	0.0	2521.4	2456.9	...	2594.0	2962.3	2878.6	2401.7	3211.3
3	1446.5	2873.6	2294.7	0.0	2689.0	...	927.1	1960.0	1538.0	3001.4	1870.7
4	3493.3	1655.7	2415.4	3131.0	0.0	...	2715.1	2516.4	2533.3	827.1	2866.0
	...	...	...	...	...	...	...	...	...	...	...
474	1721.5	2276.6	2583.5	974.2	2270.7	...	0.0	1337.8	915.8	2583.1	1273.7
475	1612.2	1246.1	3331.3	2059.3	2432.7	...	1398.5	0.0	659.3	2033.8	1191.6
476	1842.5	1788.1	3079.2	1807.2	2391.1	...	1146.4	631.9	0.0	2362.1	1215.2
477	3613.5	1468.7	2387.6	3251.2	880.4	...	2835.3	2391.3	2653.5	0.0	2986.2
478	810.1	1616.7	3039.0	1791.9	2402.8	...	1154.3	866.7	1092.1	2404.4	0.0

P-Median Models and Solvers

A p-median model is one of the fundamental approaches in facility location problems, aimed at optimally positioning P facilities to serve a set of demand points while minimizing the total weighted distance between facilities and demand points (ReVelle & Swain, 1970). The model can be mathematically formulated as follows:

Let:

- I be the set of demand points ($i \in I$)
- J be the set of potential facility locations ($j \in J$)
- d_{ij} be the distance or cost between demand point i and potential facility j
- y_i be a binary variable indicating if location i is selected as a facility (1) or not (0)
- x_{ij} be a binary variable indicating if demand point i is assigned to facility j (1) or not (0)

The comprehensive p-median model can be formulated with the following objective function and constraints:

Minimize: $\sum_i \sum_j d_{ij} x_{ij}$

Subject to:

1. Single Assignment Constraint: This ensures each demand point is assigned to exactly one facility.

   $\sum_j x_{ij} = 1; \forall i \in I$

2. Facility-Assignment Relationship: This ensures demand points can only be assigned to selected facilities.

   $x_{ij} \leq y_j; \forall i \in I, \forall j \in J$

3. Number of Facilities Constraint: This fixes the total number of facilities to be located at P.

   $\sum_j y_j = P$

4. Binary Constraints

   $x_{ij} \in \{0, 1\}; \forall i \in I, \forall j \in J$

   $y_j \in \{0, 1\}; \forall j \in J$

This formulation provides a clear understanding of the problem structure, where:

- The objective function minimizes the total weighted distance between demand points and their assigned facilities
- The first constraint ensures each demand point has exactly one serving facility
- The second constraint links the assignment variables (x_{ij}) with the location variables (y_j)
- The third constraint sets the exact number of facilities to be located
- The fourth constraint defines the binary nature of the decision variables

This model formulation, while comprehensive and theoretically complete, can be simplified for specific implementation purposes, particularly when working with heuristic approaches like genetic algorithms.

Given the NP-hard nature of facility location problems, various formulations of the p-median model have been developed to address different implementation needs. While the comprehensive formulation above provides a complete mathematical representation, a more compact version can be particularly advantageous for certain solution approaches, especially when working with heuristic methods. This simplified formulation reduces the number of decision variables while maintaining the essential characteristics of the p-median problem. In our study, we employ the following compact formulation that is particularly well-suited for genetic algorithm implementation:

A binary variable p-median model is commonly used in facility location optimization. Rosing et al. (1979) defined a p-median model with three constraints and a user-defined number of binary variables as follows:

Minimize:

$$\sum_i \sum_j d_{ij} x_{ij} \tag{1}$$

Subject to:

$$\sum_j x_{ij} = 1 \forall i \tag{2}$$

$$\sum_j x_{jj} = P \tag{3}$$

$$x_{ij} - x_{jj} \leq 0 \forall i, j \tag{4}$$

Where:

- d_{ij} is the distance matrix value or the cost of the edge between nodes i and j.
- x_{ij} is the decision variable indicating if node i is allocated to a facility j in which case $x_{ij} = 1$, otherwise $x_{ij} = 0$. $x_{jj} = 1$ only if node *j* is a facility.

Constraint (2) ensures that every demand point is assigned to exactly one facility, constraint (3) ensures that we have exactly *P* number of facilities, and constraint (4) indicates that no demand point *i* is assigned to *j* unless there is a facility.

Genetic Algorithms

Heuristic algorithms offer a practical alternative for exact solvers in p-median problems. They trade off solution accuracy to reduce resource usage, which can grow exponentially when the problem gets bigger in size. Genetic algorithms (GA) that proceed by imitating the natural evolution process, an idea introduced by John Holland, and developed by David Goldberg in collaboration with some of his students (Denning, 1992).

A potential solution to the optimization problem is a data structure named also chromosome or individual. A collection of individuals in the same generation forms a population. New generations are produced by iterating through user defined evolutionary operators until a stopping condition is met. Drawing inspiration from the work of Satoğlu et al. (2016), the current GA operators are described as follow:

- The **chromosome** is a list of integers representing the IDs of the nodes proposed as a distribution center. Chromosomes are assigned a fitness score calculated using the objective function defined by the model. A lower score indicates shorter transportation distances, making the chromosome fitter.
- The **selection** operator defines strategies to select the most sutable individuals from the current population. Here, the selection of individuals that will constitute the new generation is based on ranking.
- The **crossover** operation combines the attributes of two individuals to create a new one, potentially inheriting the strengths of both parents and resulting in a more evolved solution. A safe crossover avoid generating invalid individuals that violate model constraints. To do so, we use exchange vectors (a list of genes that are present in one parent but absent from the other) from both parents, before transferring some genes from one parent to another.
- The **mutation** operator slightly modifies an individual's genes, helping the optimizer to avoid being stuck in local optima. It is a crucial part of the evolution process.

GA Implementation

After defining the initial population, GA proceed by iteration cycles formed from the succession of GA operators in the following order: selection, crossover, mutation, and evaluation of fitness. Some operators requires various input parameters (Table 4). For example, at the mutation level, we can adjust the mutation depth (percentage of genes in each chromosome to be mutated) and mutation probability,

To evaluate the parameters impact on the final solution and the running time, we ran multiple GA instances (48 in total) with all possible parameter combinations.

Table 4

GA parameters

Parameter	Description	Values
Mutation percentage	The percentage of genes in each chromosome that can be mutated	0.01, 0.05, 0.1, 0.15
Mutation probability	The likelihood that mutation occurs on any given chromosome	0.1, 0.2, 0.3
Generation size	The number of individuals in the population	10, 40, 70,100
Number of iterations	The number of iterations or generations	500

Mixed Integer Programming (MIP)

We applied the Mixed Integer Programming (MIP) approach, implemented with the PuLP package and the GLPK solver. PuLP is a Python library used for formulating and solving MIP problems. It allows describing optimization problems as mathematical models and acts as an interface for MIP solvers. GLPK (GNU Linear Programming Kit) is an open-source solver for linear programming and mixed integer programming problems.

Results

The optimization of the PTT distribution network was approached using two distinct methods to assess their suitability for the current problem size. The performance of the GA implementations and the MIP approach demonstrates promising results in improving the current location network by reducing travel distance. Additionally, the analysis provides valuable insights into the impact of GA operator parameters on the evolution of the generations across iterations, as well as on time consumption.

Figure 1

Fitness score and Mutation percentage

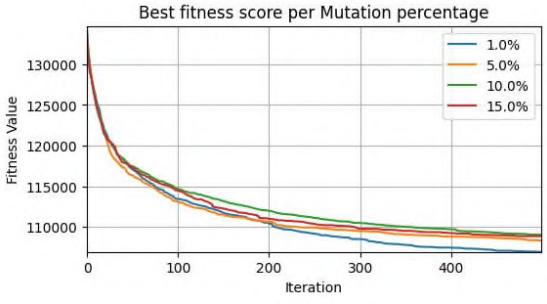
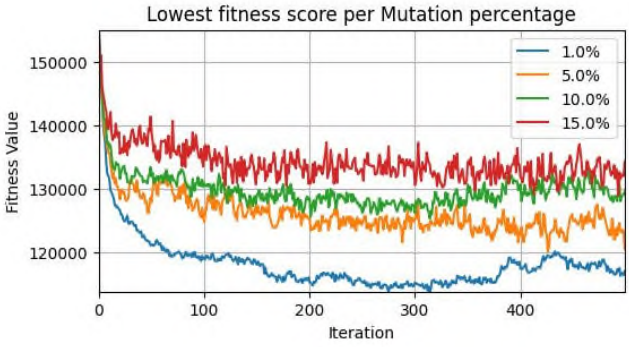


Figure 2

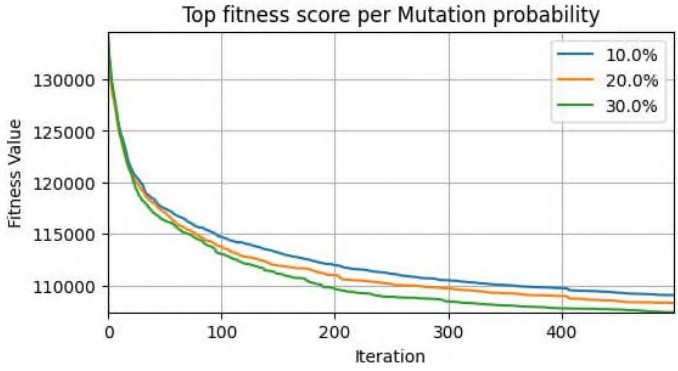
Lowest Fitness score and Mutation percentage



A higher mutation probability does not always improve performance. Although higher mutation rates can perform well in the early iterations, lower mutation probabilities tend to be more effective as the algorithm nears the optimal solution. High mutation rates can cause significant fluctuations in the performance of chromosomes (Figure 1 and Figure 2).

Figure 3

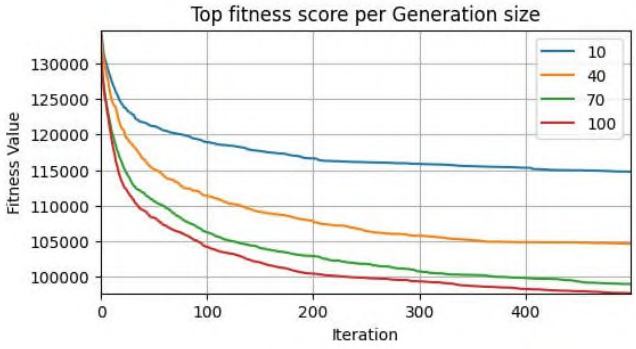
Top Fitness score and Mutation probability



The results suggest that mutation probability can enhance efficiency, as shown in Figure 3.

Figure 4

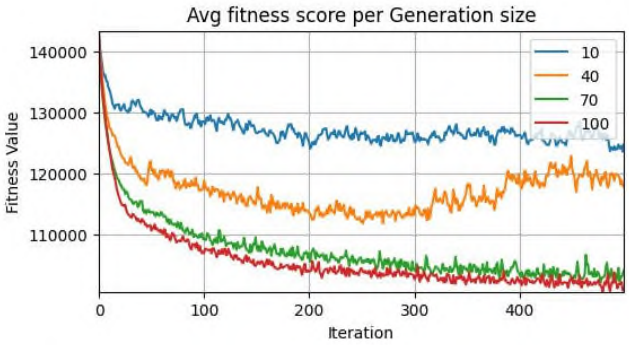
Top Fitness score and Generation size



Generation size significantly affects the average fitness of the populations. Larger populations generally result in a better average fitness (Figure 4 and Figure 5), even though they include more individuals with both high and low fitness levels.

Figure 5

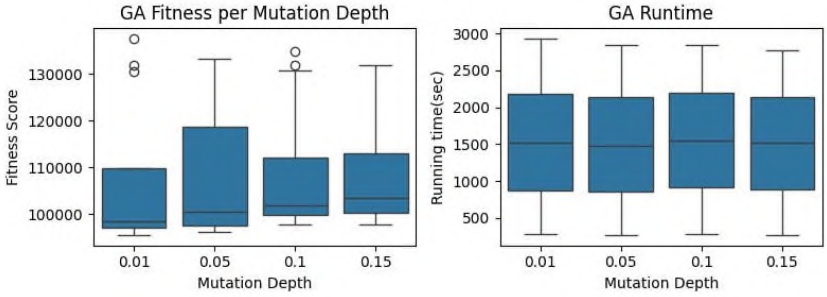
Average Fitness score and Generation siz



These results align with the findings of Kolahan and Doughabadi (2012), who demonstrated that the performance of GA implementations varies depending on evolution operators, chromosome structure, and the tuning of parameters.

Figure 6

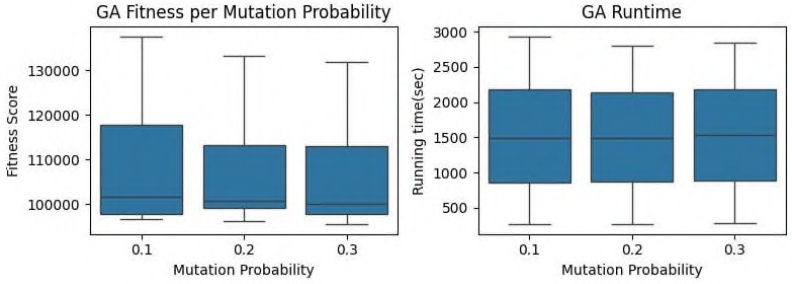
GA fitness and running time according to Generation size



The mutation level can have a slight impact on performance without significantly affecting the running time (Figure 6) and the variations in mutation probability did not have a significant impact the running time (Figure 7).

Figure 7

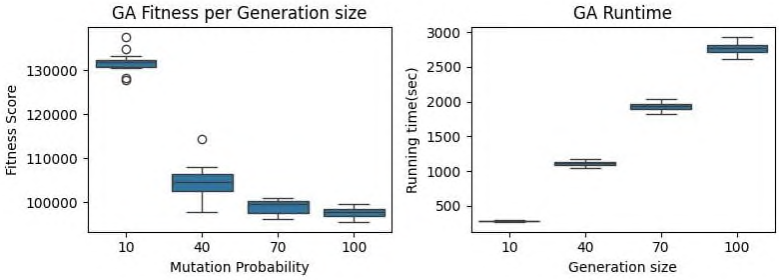
GA fitness and running time according to Mutation probability



In terms of time consumption, generation size and the number of iterations significantly affect the running time (Figure 8). Other parameters do not appear to have a major impact on the overall execution time.

Figure 8

GA fitness and running time according to Mutation probability



The best GA chromosome is obtained with the characteristics highlighted in the Table 5:

Table 5

Optimal GA parameters

	Mutation Probability	Mutation Level	Genration size	Iteration number
Parameters	(**0.01**, 0.05, 0.1, 0.15)	(0.1, 0.2, **0.3**)	(10, 40, 70,**100**)	**500**

In overall, the optimal solutions from both approaches produced better solutions than the current situation and in acceptable time. However, GA only approached the optimal exact solution provided by MIP approach (Table 6).

Table 6

Results description

	GA	MIP	Current situation
Fitness score	95.349,7	90.411,59	154,218.99.
Running time (sec)	2785.06	272.96	-

The below maps (Figure 9 and Figure 10) depict the suggested locations on a section of Istanbul city, the blue locations represents ordinal nodes, and the other ones the Distribution centers.

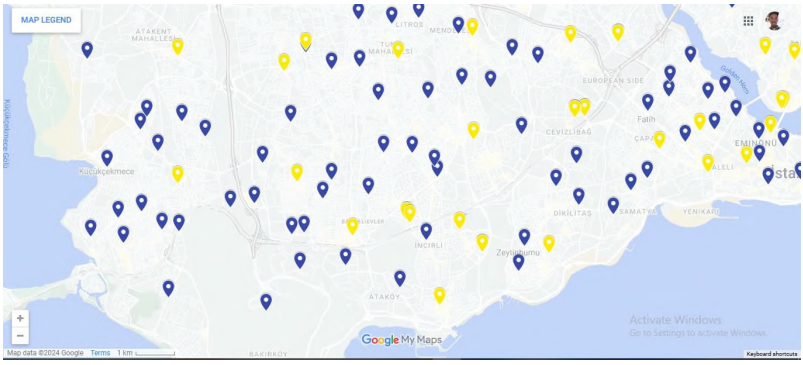
Figure 9

Results obtained from GA implementation (Fitness score: 95.349,7)

The below maps represents the current locations on a similar section of Istanbul city

Figure 10

The current situation of the PTT distribution network (Fitness: 154,218.99)



Conclusion

This research examines the application of two optimization methods to enhance the efficiency of the PTT transportation network by minimizing travel distance. Both techniques exhibited encouraging outcomes, with the Genetic Algorithm approach striking a favorable balance between solution quality and computational efficiency. The GA implementation was able to achieve a fitness score of 95,349.7, which significantly improved upon the current PTT network configuration (fitness score: 154,218.99). While the Mixed Integer Programming approach provided the best results with a fitness score of 90,411.59, the GA offered a good compromise between solution quality and computational time, with a longer execution time of 2,785.06 seconds compared to 272.96 seconds for MIP. The analysis of GA parameters indicated that mutation probability and generation size play a crucial role in determining the overall performance, with lower mutation rates and larger population sizes generally yielding better results as the algorithm progresses. The findings of this study demonstrate the viability of both MIP and GA for optimizing the PTT distribution network, with the choice depending on the specific requirements and constraints of the organization.

The results suggest that GA can be a viable option, especially for larger-scale problems where MIP may become computationally expensive or impractical. For the current problem size of 134 distribution centers across 479 locations, both methods demonstrated promising results in improving the efficiency of the PTT distribution network. However, in situations where obtaining the exact optimal solution is not crucial, the GA approach can offer a good balance between solution quality and computational time.

Key insights from the study include the importance of tuning GA operator parameters, such as mutation probability and generation size. Higher mutation rates, while beneficial in the early iterations, may introduce fluctuations that reduce performance as the algorithm converges. The results show also that GA may be suitable for large-scale problems where exact optimization is computationally expensive or impractical; MIP remains the more precise option when exact results are required.

Future work could focus on further refining the GA's parameters or exploring hybrid methods that combine the strengths of both approaches, potentially achieving faster convergence toward the optimal solution. The codes are available on github repo: https://github.com/Irakoze-A/PTT-genetic-algorithm, and a web application to run the GA implementations described in this work is available.

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Chapter 4

A Survey on Feasibility of Educational Certifications Verification Using Blockchain

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Abstract

The verification of educational certifications is a critical process for ensuring the authenticity and credibility of academic achievements. However, traditional verification methods are often cumbersome, time-consuming, and vulnerable to fraud. With the advent of blockchain technology, there is an opportunity to create more secure, transparent, and efficient systems for managing and verifying educational credentials. Blockchain, with its decentralized and immutable structure, offers a promising solution for addressing issues such as document falsification, duplication, and the complexity of verification processes. This paper explores the feasibility of using blockchain technology for educational certification verification by conducting a comprehensive narrative review of research articles published between 2017 and 2022. The study focuses on how blockchain can enhance the security, reliability, and efficiency of educational certification systems, while also addressing the broader challenges faced by educational institutions in managing certifications. Through this review, we identify the key advantages of blockchain technology, including its potential to create tamper-proof records, streamline the verification process, and provide a more transparent framework for both institutions and employers. The research also highlights the growing global trend of integrating blockchain into educational systems, signaling a shift towards more secure and automated verification methods that could transform the way academic credentials are managed. By examining case studies and current applications, this paper aims to provide insights into the practical implementation of blockchain-based educational certification systems and to contribute to the growing body of literature in this evolving field.

Keywords Verification · blockchain · educational certifications · digital credentials · fraud prevention

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Introduction

In the digital age, the demand for secure and efficient methods of verifying educational certifications has become increasingly important. With the widespread digitization of documents, many institutions still rely on traditional methods that are susceptible to fraud, forgery, and delays in verification. Educational institutions and employers face significant challenges in ensuring the authenticity of certificates, which can lead to hiring mistakes and reputational damage (Rane et al., 2020).

Blockchain technology, introduced by Satoshi Nakamoto in 2008 as the backbone of Bitcoin, has evolved significantly beyond its original application in digital currencies (Casino et al., 2019). Blockchain's decentralized, transparent, and immutable structure offers a promising solution for addressing the challenges associated with the verification of educational credentials (Shrivastava et al., 2019). By storing educational certifications on a blockchain, institutions can ensure that records are tamper-proof and easily verifiable (Raimundo et al., 2021).

The purpose of this study is to explore how blockchain technology can be used to verify educational qualifications. We conduct a narrative review of studies published between 2017 and 2022 that discuss the integration of blockchain into educational systems, focusing on its potential to combat fraud and improve the efficiency of certification verification processes. This paper aims to contribute to the growing body of knowledge by analyzing case studies and research articles to identify best practices for implementing blockchain-based educational certification systems (Castro & Manuel, 2021).

Research methodology

This study was conducted with the aim of understanding the correctness of educational certifications using blockchain. This research is a narrative review in which articles certifying educational qualifications in the world's top databases during the years 2017-2022 are searched and analysed on a case-by-case basis. Data were collected from Elsevier, Science Direct and Springer online databases using certifications. This research has been done in two stages. In the first step, the keyword blockchain is searched. In the second step, the keyword of educational certifications is combined with blockchain as shown in Table 1 and Figure 1.

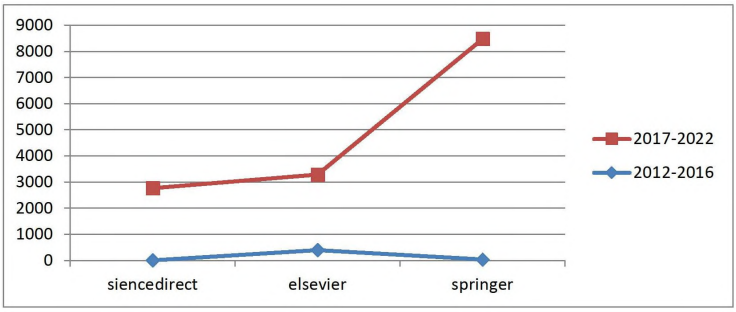
Table 1

Article numbers based on the keywords

	Web Site	Keywords	Number of articles
2012-2016	https://www.sciencedirect.com/	Education + Blockchain	10
2017-2022	https://www.sciencedirect.com/	Education + Blockchain	2762
2012-2016	https://www.elsevier.com/	Education + Blockchain	403
2017-2022	https://www.elsevier.com/	Education + Blockchain	2888
2012-2016	https://link.springer.com/	Education + Blockchain	36
2017-2022	https://link.springer.com/	Education + Blockchain	8446

Figure 1

Article numbers based on the keywords



As it can be seen, since 2012-2016, the use of blockchain in educational certification verification has not been discussed much, but from 2017 to 2022, this has become a global trend and we have seen an increase in articles, so we chose articles from 2017 to 2022.

Educational Certification Challenges

Certification fraud is one of the most pressing issues faced by educational institutions. The traditional processes for verifying academic credentials are often manual, prone to human error, and susceptible to forgery. The integration of blockchain technology into higher education certification workflows provides a solution to this challenge. Authors like (Castro & Manuel, 2021) have demonstrated that blockchain can streamline the verification process by creating an immutable, transparent, and secure system for storing and verifying certifications. This method simplifies the authentication process for both graduates and employers, making it easier to confirm the legitimacy of educational qualifications quickly and reliably.

Another critical challenge in the certification process is the cost and accessibility of verification services. In their study, (Oliver et al., 2018) introduced two financial models designed to balance the cost of certification services between graduates and employers, both of whom benefit from reliable verification. These models aim to provide low-cost, easy-to-verify certifications that meet the needs of students and employers across multiple geographic markets. The authors concluded that using blockchain technology in the certification business could create a sustainable market, particularly within the EU, as it addresses the demand for efficient, cost-effective credential verification.

Document duplication is another significant problem that educational institutions face. In many cases, it is difficult to detect forged or duplicated certifications, leading to potential fraud. Blockchain technology offers a robust solution to this issue by making stored information immutable. As (Sanjekar & Balaji, 2022) notes, once a certification is stored in a blockchain, any attempt to alter it changes the hash value of the block, rendering it invalid. This built-in security ensures that certification records are tamper-proof, providing a high level of trust and security for educational institutions and employers alike. By storing certifications on a blockchain, institutions can eliminate the risk of document duplication and fraud.

The complexity of the verification process also presents challenges in both public and private sectors, where confirmation activities are often manual and cumbersome. (Prathibha et al., 2021) highlights that the traditional verification method can be improved by using blockchain to store digital certificates and their associated digital signatures. In this system, each certification is linked to a digital fingerprint, which is stored on the blockchain using public and private keys. This method not only

secures the integrity of certifications but also automates the verification process, reducing the need for third-party agencies and improving the overall efficiency of the system.

In low-income countries, students face additional challenges in accessing and verifying their educational credentials due to financial and infrastructural barriers. (Alnafrah & Mouselli, 2021) explored the potential of blockchain technology to create national platforms that bring together all stakeholders in education, providing a secure and inclusive system for certification management. These blockchain-based platforms could increase the internationalization of education by ensuring that students from low-income countries have access to verifiable and tamper-proof certifications. This would promote equitable education and lifelong learning opportunities, aligning with the fourth goal of sustainable development.

In summary, the challenges of certification fraud, document duplication, and inefficient verification processes highlight the need for blockchain solutions in education. By offering secure, decentralized, and efficient methods for managing and verifying educational certifications, blockchain technology has the potential to revolutionize the way academic credentials are issued and verified, addressing many of the existing limitations in traditional systems.

Blockchain and Educational Certificate Verification

In regards to scrutinize the applications of the blockchain in certifications verification, a number of valuable Works and methods have been studied. Our study reveals that the application of blockchain in in education has received a significant attention from the academic perspective. These works have a studied a wide range of blockchain features which enable strengthening the educational processes. As an instance, in (Raimundo et al., 2021) authors have integrated 37 articles on Blockchain applications in the field of higher education to provide users with up-to-date knowledge. This study concludes that it is essential to find solutions for efficiency and security related issues, such as interoperability between different platforms or algorithms and assured access-control in the ray of the possible assumption of smart contracts in higher education. (Reis-Marques et al., 2021) also in an article entitled “Applications of Blockchain Technology to Higher Education” provide a bibliometric resolution contained 61 peer-reviewed articles published in the Scopus database during the period of 2016 to 2021. This paper offers the recognition of gaps in the literature enabling studies on the subject in higher education. The article identifies the original applications of blockchain technology in higher education circa the world, also suggests subsequent investigations.

Authentication, licensing, confidentiality, ownership must be considered to review educational certifications. A research study proposed a SmartSet method, which is one of the approved platforms for block-based digital validation. This technology has been developed to validate credentials in a blockchain and to overcome the problem of forged certifications. They also cited the University of Nicosia (UNIC), for example, which uses the Bitcoin blockchain for activities such as receiving tuition for each degree, issuing diplomas in the Bitcoin blockchain, and so on. This study identified and brings up the safety issues required to accredit doctrine certifications in the block. They also propose a Blockchain-based frame for evidence schooling focusing on particular topics based on the Hyperledger Fabric Framework (Saleh et al., 2020).

The power of blockchain in data storage and sharing plays a significant role in certification verification. Using an overlap mechanism along with Blockchain technology to store real certifications digitally and firmly verify them when needed without delay is a method proposed in (Reddy et al., 2021). The proposed order is a consortium blockchain among universities, and companies. Universities first add the students’ testimonial and subsequently the companies or any other testifier can verify the credentials by using student’s Aadhar number or bargain ID of the certificate. The data cumulative in

a blockchain will be protected as no one can tamper it or add new transactions to it with a back date. The generated unique ID for each bargain is later used to check the testimonial. This system can be used by all the universities and colleges, in order to put out extra security to the testimonial and the students' data. They believe that the problem of fake certificates can be eliminated and there will be no discussion about the validity of other certifications. In the future, this could be extended to integrate any type of documentation, not only for the education sector, but also for the public sector where digital certification stamping is required. It can be tracked not only to store student sign information, but also to store their occupational and experimental data, as well as using this proposed system (Reddy et al., 2021).

Smart Contract

The Role of Smart Contract in Blockchain-Based Educational Certification Systems

Smart contracts serve as the technological linchpin in blockchain-based educational certification systems, enabling the automated, secure, and efficient management of academic credentials. These self-executing agreements eliminate the need for intermediaries by automatically triggering processes such as credential issuance, verification, and revocation once predefined conditions are met. This automation not only enhances transparency and reduces the risk of fraud but also ensures that all transactions are recorded immutably on the blockchain, making them tamper-proof. By streamlining operations and fostering decentralized trust, smart contracts address the critical need for authenticity and accuracy in educational certification. However, their implementation is not without challenges; issues such as ensuring code security, managing privacy concerns, and integrating with existing infrastructures, while maintaining compliance with regulations like GDPR, remain significant hurdles to broader adoption (Fekete & Kiss, 2023; Rustemi et al., 2023; Sharma et al., 2023).

Examples of Smart Contract Implementations for Credential Issuance, Verification, and Revocation

Smart contract implementations for credential issuance, verification, and revocation are revolutionizing educational certification by automating and securing the entire credential lifecycle. The Blockchain Academic Credential Interoperability Protocol (BACIP) and other frameworks like the IPFS-Blockchain model exemplify these innovations. BACIP employs Ethereum smart contracts to issue uniquely identified credentials, ensuring their authenticity and preventing tampering. This protocol's hybrid blockchain architecture enhances both transparency and privacy, while dedicated smart contracts maintain an immutable revocation list, ensuring that invalid credentials are universally recognized. Similarly, the IPFS-Blockchain framework uses smart contracts to securely store and manage credentials on the blockchain, with the Interplanetary File System handling large, encrypted data sets. In Tanzania, a proposed model leverages blockchain's decentralized nature to streamline credential verification, allowing recruiters to independently verify authenticity and manage revocations efficiently. These examples underscore the transformative potential of smart contracts in reducing fraud and enhancing the global interoperability and reliability of educational certifications (Alamiro & Moya, 2024; Said et al., 2023; Sultana et al., 2023).

Security Considerations and Best Practices for Developing Smart Contracts in Blockchain-Based Educational Certification Verification

Developing smart contracts for qualification certification verification necessitates a meticulous focus on security, given the immutable and decentralized nature of blockchain technology. This immutability demands that potential vulnerabilities be addressed proactively, as post-deployment corrections are impossible. To mitigate security risks such as re-entrancy attacks, integer overflow errors, and unauthorized access, developers must prioritize rigorous code audits, employ both static and dynamic analysis, and utilize formal verification techniques to mathematically validate the contract's logic. Established secure coding standards, such as those provided by OpenZeppelin, should be followed, with mechanisms like multi-signature authorization integrated to enhance security. Continuous monitoring, periodic security audits, and thorough pre-deployment testing in simulated environments are essential to ensure the long-term integrity and reliability of these smart contracts. Additionally, a modular design approach allows for updates without compromising security, ensuring that qualification certification systems remain both trustworthy and resilient against emerging threats (Alaba et al., 2023; Jordanus & Van Raalte, 2023; Santamaría et al., 2023; Vacca et al., 2024).

Automation and Streamline Certification Processes using Smart Contracts

Smart contracts are revolutionizing the educational certification landscape by automating and streamlining processes with unprecedented efficiency, accuracy, and security. By eliminating manual intervention, these self-executing contracts ensure that certificates are issued, verified, and revoked based on predefined conditions, such as course completion or payment, without the need for intermediaries. This automation reduces delays, errors, and fraud, while enhancing transparency and trust through the blockchain's immutable ledger. Systems like K12Net and Blockchain Powered Student Certificate Validation (BPSCV) exemplify this transformation by integrating smart contracts with blockchain technology and decentralized applications, enabling real-time tracking, secure storage, and seamless verification of academic credentials. These innovations not only optimize administrative tasks but also build a more reliable and interactive educational environment, where all stakeholders can easily access and validate credentials with confidence (Kalinyazgan & Ozpinar, 2024; Rani et al., 2024; Sabitha et al., 2024; Thuy Tien & Anh Linh, 2024).

Potential Challenges and Limitations of Smart Contract Usage in Educational Certification Systems

The implementation of smart contracts in educational certification systems holds great promise but faces a series of challenges and limitations that must be carefully addressed for effective adoption. Data privacy and security stand as critical concerns, particularly in light of regulations like GDPR that require flexibility in modifying or deleting personal information, conflicting with blockchain's immutability and transparency. The high cost of developing and maintaining blockchain infrastructure poses another hurdle, especially for smaller institutions. Scalability issues further complicate matters, as blockchain networks may struggle to handle the large volume of transactions needed in widespread educational use. Additionally, the integration of blockchain with existing systems is both technically complex and costly, while stakeholder acceptance remains limited due to unfamiliarity with the technology. Issues such as the ambiguous ownership of digital resources and vulnerabilities within the blockchain network itself compound these challenges. To overcome these limitations, integrating cloud storage, establishing robust legal frameworks for data ownership, and providing extensive education

and support are essential steps (Fekete & Kiss, 2023; Wang et al., 2023; Widyasari et al., 2024; Younas & Al Wahaibi, 2023).

Merkle Tree as an Encryption Method for Educational Certifications

In cryptography and computer science, a hash tree or Merkle tree is a tree in which every "leaf" is labelled with the cryptographic hash of a data block, and every node that is not a leaf is labelled with the cryptographic hash of the labels of its child nodes. The feasibility of implementing the Merkle Tree in blockchain-based educational certificates has been studied in various studies. Saito tries to achieve selective lightweight disclosure to protect the privacy of certification holders. They proposed an XML template for certifications that can hide arbitrary elements using an encryption hash function and salts, and allow the use of digital signatures more efficiently. The JSON format can also be converted to such XML. The existence of these certifications can be effectively proven by displaying several structures such as the Merkel tree and storing its roots in the block. They showed that their proposal had many advantages over the well-known methods that show the certification itself as a Merkel tree and partially conceal it (Kenji & Watanabe, 2021). Mukta in a research examined an example of the application of a known method using the Merkel tree to indicate validity, and identified where the Merkel root was digitally signed (Mukta et al., 2020).

IPFS as a Distributed, Secure Storage for Educational Certifications

The Inter-Planetary File System is a protocol, hypermedia and file sharing peer-to-peer network for storing and sharing data in a distributed file system. IPFS uses content-addressing to uniquely identify each file in a global namespace connecting IPFS hosts. IPFS system can use several hashing algorithms to procreate hash for certification. Recently, the potential features of IPFS to secure educational certificates have been studies widely. Authors in (Abhishek et al., 2021) first examined cloud computing and proposed a decentralized and reliable mechanism for cloud data origin using the Ethereum blockchain platform, IPFS, and a scalable agreement mechanism. PoW is the consensus algorithm currently used in the Ethereum blockchain. The Proof of Work (PoW) which is a consensus mechanism requires a lot of computing power to process data in the Chinese blockchain. Therefore, they implemented the Stock Evidence Consensus (POS) algorithm in Ethereum to improve the efficiency of the cloud computing data source mechanism. They demonstrated the performance of a PoS-enabled source framework in a multi-node experimental medium. The results show that Proof of Stake (POS) which is another consensus mechanism works better than PoW for cloud data sources. Authors in (Vatsaraj et al., 2021) developed and tested a decentralized certification storage system based on the increase in algorithmic cyber-attacks using a private blockchain network based on the Ethereum and (IPFS). Interim results show that the proposed solution can be implemented on a scale for specific uses, including confidential certifications of private and public institutions. (Shrivastava et al., 2019) in an article entitles “A Decentralized Way to Store and Authenticate Educational Certifications on Private Blockchain” state blockchain minimizes the chance of data loss. They believe that Consensus Algorithm is the mathematical way to cessation the skulduggery over Blockchain. They introduced the IPFS, a decentralized peer-to-peer network that can be used to store certifications, media files, or any other type of domain. It works much like torrent software in that each main file is split into small chunks with a fixed address and can be seeded by different counterparts. Similarly, IPFS converts file into little encrypted chunks and build a hash from that. Now this file can stay on divided network and can be retrieved by using designated Public Private Key (PPK) mixture. This PPK is shared by Ethereum’s inbuilt mechanism of digital endorsement. IPFS system can use several hashing algorithms to procreate hash for certification. Another study which has implemented IPFS as a bloach-chain based distributed file system to provide secure storage for educational certificates and combat fraud, proposes a system and Ethereum IPFS

for storing, retrieving and authenticating educational certifications, as well as simplifying the whole process of reviewing and producing results (Sagar et al., 2022). The proposed system consists of three main modules: acceptance, tests and results.

Other Fields That Benefit from Data Verification Using Blockchain

The certification verification use case of blockchain has a wide range of applications. A globally approved electronic voting, health care record management, identity management systems, access control systems, decentralized notary (focusing on intellectual property protection) and supply chain management are some of these applications. There are many suggestions for electronic voting today. But certainly a simpler platform to achieve this is a Bitcoin-based digital blockchain. A platform for institutions to store student information with high security has been proposed in (Dhyani et al., 2022). This Ethereum-based platform is reliable, cost-effective and scalable, and delivers certifications through a web interface. The platform is based on robust JavaScript logic and uses the blockchain to enforce certification invariance, and the backend connects to the user junction using the web3.js library. In addition, the platform provides statistical collation of these records with other students and helps the employer appraise the proficiency of the student being hired. It is not just the education filed which is suffering from the certification frauds. (Ramya et al., 2019) raised the issue of forgery of real estate certifications and believe that this phenomenon can be eliminated and the issuance of the certification can be accelerated with a blockchain-based application utilizing a private license and multi-chain that eliminates the need to prove the truth. Execution of user registration file includes registration of certifications in the blocks and its approval with certifications stored in the digital shelf, thus reducing forgery of certifications. Researchers in a work in 2022 suggested the use of Blockchain technology at the time of Covid 19, when hospitals could quickly examine patient information. Shares data based on diagnosis and treatment. If they understand the disease better, they can find a cure soon. Therefore, there is a need to protect all data against breaches. They suggested a way to store patient data in the Chinese blockchain that could be useful in resolving the crisis (Gupta & Rahul, 2022). Another study provided a framework in the field of blockchain and health that emphasizes data sharing using a decentralized database in blockchain technology. Consensus on Blockchain technology ensures that data is legitimate and secure. The convergence of these two technologies can give very accurate results in terms of machine learning with the security and reliability of Blockchain technology (Vyas et al., 2019).

One type of personal data is health data. Because this information is vital and a person may need it in another hospital or in another city or in another country, there should be a system that is secure and transparently stores and retrieves all this information, the researchers suggest use of blockchain system. Likewise system, users sole are in control of their own data by granting or denying access (e.g., to pharmacies or insurance companies) to it.

Today, identity management systems are frequently intensive and immaterial from each other. The idea of a self- monarch personality system based on blockchain is no different from the idea of blockchain based personal health record they can also be said to be interchangeable. Transparency is a key issue in all of the applications covered in this article. A blockchain uses reliable storage to read and write data. This prevents the data from being altered, tampered with, and stable. The blockchain provides data stored internally (Maesa & Paolo, 2020). Lie in his paper conceptualize a decentralized blockchain-based framework for document collecting called CrowdBC, in which the applicant's task can be solved with a large number of workers without relying on any third-party trust, and user privacy can be guaranteed. In particular, they introduce an architecture by implementing a prototype software in the Ethereum Public Test Network with real-world datasets. The test results show the feasibility, usability and scalability of their proposed crowd funding system (Li et al., 2019). Authors in a study

conducted in 2020 have proposed a framework called MudraChain for automatic check clearance, in which clearance operations are performed by the blockchain network instead of the existing Cheque Truncation System (CTS). The proposal includes the following steps: (i) a multi-level authentication scheme to secure the Blockchain framework among participating financial stakeholders; (b) a rapid response code generation (QR) algorithm that performs digital signature of checks. And (iii) a new two-factor authentication protocol for creating a One-Time Password (OTP) for secure funds transfers. The results obtained against the advanced approaches are examined to show the superiority of the proposed framework. Thus, MudraChain enables a unified flow of blockchain clearance operations for the payer and recipient without any intermediaries. Finally, it examines the requirements for building a secure application for check settlement with respect to Decentralized Blockchain 4.0 applications (Kabra et al., 2020). Saberi in her work stated that four categories of barriers to blockchain technology assumption have been famous. Inter organizational, intra organizational, technological and foreign barriers. They propose future research propositions and orientations that can provide insights into overcoming barriers and adopting Blockchain technology for supply chain management (Saberi et al., 2018). Authors in (Sonnino et al., 2020) provide unlikable elective revelation, but with higher charge. Verification, for example, charge gas, or bargain fee, in their Ethereum implementation, whereas their proposal does not require gas for verification. A recent study in 2022 proposed a blockchain-based online privacy management solution to address user privacy breaches. Their proposed solution uses a publicly licensed blockchain model with various reliable encryption schemes, zero proof knowledge standards (ZKPs) and digital signatures (DSs) within the integrated Fog-Blockchain framework that is also General Data Protection Regulation (GDPR)compliant and highly secure. It does not violate users' privacy (Baniata & Kertesz, 2022).

Conclusion

The purpose of our study is to identify the main applications used to verify educational certifications using blockchain in order to contribute to the literature in this field of study. Therefore, we identify two approaches to support this area of interest: blockchain and educational certification verification. The relationship between blockchain and education is not hidden from anyone, and this topic should be taught to all organizations. If we want to add more value to the innovation process in higher education and provide future programs based on customer needs, we must consider blockchain technology in the field of education because we consider security to be an important part of the blockchain process. Especially in verifying certifications containing scientific details and providing a reliable solution to prevent any scientific fraud. In this research, we discussed various applications of blockchain in the field of certifications. The most visible problem is the frequent use of Ethereum-based algorithms in the field of certification validation. It does not matter whether these certifications are personal or educational. or even residential land. According to the investigations conducted in this research, most researchers presented Ethereum-based solutions, and as a result, it can be claimed that Ethereum-based algorithms are more efficient in the field of certification authentication. Also, most researchers have used web-based software or Excel to report their work, which shows how easy it is for them to conduct research. For the future works, we can check the DLT method in articles related to Hyperledger and suggest a solution to improve the security of academic certifications. Also, evaluating the performance of the Ethereum blockchain by considering various parameters such as changes in the difficulty level, load, network size and consensus algorithms in the evaluation and verification of academic degrees can also be one of our suggestions for further research.

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Chapter 5

Analyzing Digital Transformation Maturity Models as an Effective Tool to Enhance the Role of SMEs in Regional Development

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Abstract

With its increasingly recognized importance, digital transformation contributes to businesses in many ways. However, the complex nature of digital transformation poses a challenging factor for businesses. A systematic approach is required to overcome this complexity. The question of where, how, and with which resources to start digital transformation is a topic frequently addressed in the literature. In this context, various digital transformation maturity models have been developed to serve as guides for businesses in preparing their digital transformation roadmaps. Through these models, businesses can analyze their current situations and prepare a roadmap in line with their digital transformation goals. Digital transformation is not merely a tool used to improve business processes; it is also a tool employed to gain competitive advantage for businesses. The examination of Digital Transformation Maturity Models plays a crucial role in enabling SMEs (Small and Medium-sized Enterprises), which have a significant role in regional development, to undergo digital transformation. This process can contribute to increasing their competitiveness, gaining access to a qualified workforce, improving their processes, enhancing their abilities to offer new products and services, acquiring agility in their operations, and making substantial contributions to sustainable business models. However, the technical knowledge and skills required for digital transformation, combined with the characteristic features of SMEs, lead to differentiation in their digital transformation initiatives compared to larger firms. Designing every element of the digital transformation processes in a manner suitable for SMEs will facilitate their digitization processes, contributing to regional development. In this context, the aim of the study is to analyze the suitability of existing digital transformation maturity models as tools that contribute to the role of SMEs in regional development. The study involves a literature review covering the roles of SMEs in regional development, the importance of digital transformation for SMEs, digital transformation maturity models in general, and specifically those tailored for SMEs.

Keywords Digital transformation · digital maturity · digital transformation maturity models · small and medium-sized enterprises (SMEs)

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Introduction and Theoretical Background

Globally, the significance of Small and Medium-sized Enterprises (SMEs) for regional development is frequently emphasized by academics and policymakers. Similarly, for SMEs, digital transformation holds an equally crucial role. The increasing normalization of digital transformation in light of technological advancements, particularly its substantial impact on the level of development and competitiveness, underscores the need for SMEs, which play diverse roles in regional development, to evolve in this regard and adapt to new market conditions. There is no one-size-fits-all formula for digital transformation, regardless of the size of the businesses. Given the structure of digital transformation, it necessitates the simultaneous management of various new and distinct technologies and applications. Determining where to initiate the transformation and the direction it should take must be meticulously defined. Analyzing specific needs and the current state of each business and formulating a strategy and plan in alignment with the results of this analysis is imperative. However, the absence of a formula for digital transformation does not imply that a systematic approach cannot be applied to it. In this context, there are "Digital Transformation Maturity Models (DTM Models)" in the literature that can serve as guides for digital transformation. With DTM Models, current situation analyses can be conducted, and a roadmap can be outlined. Upon reviewing the relevant literature, it can be noted that there is a considerable number of DTM Models available. While these models are developed in two main types, theoretical/academic-focused and practical/industry-focused, they ultimately serve the same purposes: 1) Conducting a current state analysis and 2) Creating a strategic roadmap for digital transformation. It can be said that these models generally share common dimensions, and these dimensions are shaped within the framework of organizational management. Through DTM, dimensions are assessed based on established criteria, current state analyses are conducted, and a maturity level is determined. The identified maturity level indicates the readiness of the company for digital transformation. This readiness serves as a precursor to the strategic steps that will be taken.

The importance of DTM models lies in their potential to serve as a guide for SMEs, which play a crucial role in regional development and face challenges in initiating digital transformation-a prerequisite for contemporary competitiveness and sustainability. In this context, the study explores the role of SMEs in regional development, the significance of digital transformation in SMEs, DTMM, and the applicability of these models to SMEs. The scope of the study is determined within the framework of the following research questions.

- Can the role of SMEs in regional development be enhanced through DTMMs?
- Do existing DTM Models promise an effective analysis for SMEs?

The Role of SMEs in Regional Development

According to the OECD, micro, small, and medium-sized enterprises (SMEs) consist of businesses employing fewer than 250 people, with an annual turnover not exceeding 50 million euros and/or an annual balance sheet total not exceeding 43 million euros (OECD Statistics Portal, 2005). Globally, SMEs account for approximately 90% of businesses and employ over 50% of the total registered workforce, contributing up to 40% of the Gross Domestic Product (GDP). When considering informal SMEs, this contribution is anticipated to be even higher. According to World Bank data, the development of SMEs will become a high priority for many policy-making institutions globally, given that, by 2030, around 600 million jobs will be needed to accommodate the growing global workforce (World Bank, 2022). In light of these statistics, it can be stated that SMEs play a critical role in today's society and economy, and research on the digital initiatives of SMEs can contribute to the development of local and global economies.

SMEs are perceived as enterprises with a flexible organizational structure, relying more on individual effort and limited resources to survive (Levy & Powell, 1998). However, limitations in financial resources, lack of advanced production technologies, deficiencies in standardization, low levels of R&D activities, and weaknesses in social qualities such as organizational culture and leadership differentiate them from large enterprises. These factors also lead SMEs to face various challenges in competition and meeting contemporary standards (Mittal et al., 2018).

Schallmo et al. (2020) see SMEs as long-term and independently existing businesses by their nature. Therefore, especially in the face of new and radical changes like digital transformation, this situation can be challenging for SMEs. To overcome this problem, SMEs need to identify their own needs and requirements. However, due to their dynamic and practical working principles, they prefer rapid and easy pragmatic solutions, avoiding excessive reliance on theoretical approaches. On the other hand, Arendt (2008) states that the lack of knowledge and skills in digital transformation is the biggest obstacle for SMEs in the digitalization process. Practical, relevant, and understandable advice that aligns with the realities of SMEs will contribute to their motivation in meeting the requirements of digital transformation.

SMEs, as a common denominator in the economies of many countries, exhibit differences in terms of the number of enterprises, investment and employment criteria, development levels, socio-economic structures, geographical features, cultural and political characteristics. Considering their share in the economy, SMEs are seen as the basic elements that should be considered when formulating policies in countries. According to Çatal (2007), the flexible structure of SMEs is crucial in adapting to rapid changes and market conditions, playing a significant role in reaching global markets. In this context, the contribution of SMEs to economic growth and regional development is equally important. As conveyed by Çatal (2018) and reflected by Müftüoğlu (1987), a robust and healthy SME structure is an indispensable condition, the most important guarantee, and a cornerstone of economic development, political stability, and social peace.

Fiseha and Oyelana (2015) assert that SMEs contribute to employment, prosperity, reduction of poverty, and the creation of material inputs, but SMEs in developing countries also face challenges such as lack of finance, insufficient skills, and limited scope of operations. To enhance the contribution of SMEs to local economic development, support provided by local governments, the private sector, and civil society to SMEs should be increased. Fiseha and Oyelana (2015) emphasize the necessity of the participation of all sectors in creating and sustaining support for SMEs.

Moreover, they note that while SMEs can contribute to exports in the economy, this contribution is relatively small compared to their other contributions. The reasons cited for this include insufficient capital, technology, and limited human resources per operation for SMEs (Özdemir et al., 2007). Enhancing the competitiveness of SMEs and addressing their shortcomings are crucial for sustaining the mentioned roles and positioning SMEs advantageously in regional or international competition in terms of sustainable economic activities.

Researchers have extensively explored the roles of SMEs in economic and social development (Çatal, 2007; Fiseha & Oyelana, 2015; Harvie & Lee, 2002; OECD, 2019; Özdemir et al., 2007). These roles are outlined below:

- Creating more jobs per unit of capital compared to large enterprises,
- Serving as an education/preparation ground to enhance and develop the skills of workers, technicians, managers, and entrepreneurs in the industry,
- Establishing connections with larger firms in the local economy,

- Playing a significant complementary role for large corporations and transferring or developing technical knowledge,
- Reducing import requirements and thus contributing to foreign exchange savings,
- Facilitating the increase of economic and social welfare,
- Providing employment opportunities,
- Encouraging flexibility and innovation,
- Accelerating regional development and reducing disparities between regions,
- Promoting entrepreneurship.

Considering the characteristics of SMEs and their roles in economies, it can be anticipated that activities related to digital transformation and the integration of information technologies in this field will not be the same as those for large enterprises. The absence of a predefined formula for success in digital transformation and the differentiated characteristics of application areas necessitate the establishment of unique roadmaps for each venture. Given that SMEs face different constraints compared to large firms, their technological needs become challenging to address independently or without sufficient support. Consequently, the appropriateness of digital transformation maturity models developed and utilized for large-scale enterprises is being questioned and explored in academic circles for SMEs (Williams et al., 2019).

The Importance of Digital Transformation for SMEs

In our era, digital transformation, which nearly all organizations need to adapt to, has been conceptually defined differently in various studies. In a general sense, digital transformation is an ongoing process where digital capabilities redefine business processes, business models, and corporate relationships (Borštnar & Pucihar, 2021). Gökalp and Martinez (2021a) describe digital transformation as disruptive technological acquisitions that bring together new business and operational models across all sectors. Teichert (2019), on the other hand, broadly defines the concept of digital transformation as the processes through which organizations adapt to digital changes to meet the digital expectations of customers, partners, and employees. Morakanyane et al. (2017) have compared various definitions in the literature and describe digital transformation as evolutionary technological processes that enhance digital capabilities and provide added value to customer experience, business models, and operational processes.

The integration of technological innovations into companies is considered a component of digitalization processes and digital transformation. The rapid development of digital technologies has an impact on various sectors, and companies are increasingly facing a competitive environment. Therefore, companies can gain a competitive advantage by keeping pace with digital transformation (Tarutė et al., 2018). Digital transformation is positioned as a dynamic force driving change for companies. It is seen as a significant driving force for growth, productivity, competitiveness, and innovation in companies. Especially for SMEs to compete with large companies, they need to take advantage of the opportunities brought by transformation (Scuotto et al., 2021). Hence, SMEs must develop new business strategies and processes involving the use of digital technologies (Ferrari, 2012). According to Ulaş (2019), digital transformation offers opportunities for SMEs to enhance their competitiveness in local and global markets through product or service innovation and improved production processes. Looking at SMEs that have undergone digital transformation, it is observed that these businesses have strengthened their ability to gain a competitive advantage and sustain their existence over time (Crupi et al., 2020). However, in today's business landscape, especially for SMEs, they are confronted with a challenging process of digitalization. In the face of this challenging and complex situation, determining the factors

to be addressed, particularly in identifying where to begin with digital transformation, and conducting analyses related to these factors are essential.

Digital Transformation Maturity Models (DTMM)

The concept of digital maturity is commonly used as a general expression that enables organizations to analyze themselves in their journey of digital transformation and reflects where they stand. Digital maturity indicates the state of readiness or preparedness for digital transformation (Teichert, 2019). At the core of the digital transformation process lies the level of digital maturity. A roadmap is crucial in the process of digital transformation, and determining the levels of digital maturity plays a significant role in setting this roadmap (Gökalp & Martinez, 2021b). In the literature, there are various Digital Transformation Digital Maturity models presented by both industry experts (Practical/Industry-focused models) and academics (Theoretical/Academic models). The common goal of these models is to serve as a guide in identifying areas that need improvement by determining the level of maturity. As Barata and Cunha (2017) express, these models not only provide insights into the current situation but also serve as a basis for identifying areas that can be optimized for digitalization.

According to Klimko (2001), maturity models are general approaches that aim to define the level of development of an entity in businesses. Teichert (2019) defines "digital maturity" as a concept that represents the processes a company has already completed in terms of digital transformation and how well it has adapted to the digital environment to remain competitive. Chanius and Hess (2016) emphasize that digital maturity is not only associated with technological advancements but also relates to how well organizations fulfill their tasks and the flow of information among structures. This approach highlights that digital maturity is a multidimensional concept, reflecting both managerial skills and technological transformation capabilities. Organizations can reach the highest level of maturity by integrating these two capabilities optimally. Shahiduzzaman and Kowalkiewicz (2018) express that organizations can only reach the highest level of maturity when they simultaneously establish strong digital foundations (technological) and understand how to leverage this digital infrastructure in strategic decisions (managerial). Many researchers indicate that managerial skills, the relationship with environmental factors, and task-based domain-specific developments play a significant role in determining the digital transformation maturity model and progressing through maturity stages (Chanias & Hess, 2016; Shahiduzzaman & Kowalkiewicz, 2018).

Although maturity models are criticized for "oversimplifying" the complexity of organizational structures and digital transformation (Benbasat et al., 1984 as cited in Gökalp & Martinez, 2021b), they can serve as useful guides for organizations to understand their current situations and effectively manage change efforts. Berghaus (2016) stated that these models consist of specific criteria and dimensions, defining scales that can serve as indicators for determining maturity levels. Criteria corresponding to identified dimensions characterize maturity levels and, through the organization's position in relation to predefined goals, define organizational maturity development (Teichert, 2019). Maturity models provide benefits in two ways: (1) the "descriptive function" of maturity models, and (2) the "normative function" of maturity models. The descriptive function identifies dimensions that need to be developed or redesigned for the organization, while the normative function outlines the path to be followed to achieve the desired maturity level in the future (Berghaus, 2016). A maturity model essentially consists of determining dimensions, defining criteria, measuring criteria, and determining maturity levels.

Maturity models, regardless of the perspective on digitalization, generally share certain common features. Mettler et al. (2010) have defined these features as follows:

1. **Number of Maturity Levels:** The model typically includes a set of levels to indicate the maturity levels of an organization.
2. **Descriptors for Each Maturity Level:** Each maturity level has specific descriptors to characterize it.
3. **Characteristic Features Reflected by Each Level:** Each level reflects characteristic features that describe the organization's maturity.
4. **Number of Dimensions:** The model specifies the number of dimensions used to evaluate maturity levels.
5. **Activities Applicable at Each Level:** Activities that can be implemented at each level are outlined in the model.

Digital Transformation Maturity models generally focus on two themes, as outlined by Teichert (2019): General-Purpose Models which are designed to meet the end-to-end needs of an organization and can be applied across various domains; Domain-Themed Models which are the models that can serve as helpful instruments in the digital transformation of specific areas (e.g., production, engineering, etc.). Despite categorical differences, the dimensions of maturity models show similarities across many models. In this context, models generally cover the following dimensions (Aagaard et al., 2021; Berghaus, 2016; De Carolis et al., 2017; Gill & VanBoskirk, 2016; Kane et al., 2016; Schumacher et al., 2016).

- **Strategy**: Strategy outlines the actions that enable a company to shape its products, services, processes, and business methods in a competitive manner.
- **Culture**: This dimension represents the organization's digital culture. Cultivating a culture conducive to continuous learning, change, and innovation is critically important for digital transformation.
- **Organization**: The organizational dimension refers to how well an organization can organize itself and the extent to which alignment enables digital transformation.
- **Processes**: In digital transformation maturity models, the process dimension emphasizes the more effective handling of existing or emerging routines by organizations.
- **Technology**: This dimension alludes to organizations incorporating various Industry 4.0 technologies (IoT, big data, artificial intelligence, etc.) into their processes, service/product production, and digital work environments.
- **Stakeholders**: Ensuring the participation of stakeholders (customers, users, rights holders, other partners) in digital processes is crucial for value creation and establishing a digital ecosystem.

Method

In the scope of this study, a literature review was conducted to evaluate the importance of DTMMs in enhancing the role of SMEs in regional development. Accordingly, specific keywords were identified considering the research questions. These keywords were matched appropriately to the theme of the study and searched in Turkish and English on selected academic databases. Additionally, to limit the data dimension and search sensitivity obtained from the databases, filters were set to include "Keyword," "Title," and "Abstract," and the time frame for digital transformation was considered from 2002 to 2022, considering the rise of digital transformation in the last two decades. Table 1 provides the databases and keywords used in the study. In this context, it was observed that studies specifically focusing on Digital Transformation Maturity and SMEs are relatively scarce compared to others. There-

fore, the study was conducted with a focus on the studies obtained from the keyword "Digital Maturity and SME," with other keywords serving as supplementary sources.

Table 1

Search Results for Keywords in Academic Databases

Keywords	Scopus	Web of Science	Semantic Scholar	Dergi Park
"Digital transformation"	38,619	20,407	2,950,000	15,919
"Digital Maturity"	3,013	1,539	1,810,000	6,954
"Local Development and SME"	900	356	3,530	43
"Digital Transformation and SME"	467	123	732	6
"Digital Maturity and SME"	104	31	120	-

Results

Digital Transformation Maturity Models for SMEs

According to Williams et al. (2019), maturity models in digital transformation are widely used in many industries, but they argue that it is not possible to speak of a digital transformation maturity model that is entirely suitable for SMEs. However, Williams et al. (2019) expresses in their research that SMEs can partially benefit from specific digital transformation maturity models by examining them. Although a fully equipped model for SMEs may not be encountered, it can be concluded from the study that the models discussed in the research can directly contribute to some aspects of SMEs' digital transformation maturity. When considering the dimensions of the models discussed in the study, Culture and Stakeholder dimensions can be said to be among the most important factors influencing digital maturity. On the other hand, the study emphasizes the significance of common dimensions in digital transformation maturity models for SMEs, similar to their importance in large industries.

In Mittal et al.'s (2018) study, SMEs are examined within the scope of the Smart Manufacturing Maturity Model, and they analyze SMEs in nine dimensions. These dimensions show similarities with other models: Strategy, Leadership, Consumer, Products, Operations, Culture, People, Governance, and Technology. The study addresses the characteristics of SMEs and, in particular, their needs for Industry 4.0 adaptation. In this context, some prerequisites for the adoption of Industry 4.0 in the digital transformation and manufacturing field have been identified. The literature reveals the absence of a model that fully evaluates SMEs. However, the study suggests that although existing models may not be capable of creating a roadmap for SMEs in digital transformation and conducting self-assessments, they can still serve as inspiration and play a role in developing suitable models for SMEs. According to Mittal et al. (2018), existing models were developed for large-scale firms, so many of the prerequisites listed in Table 2 are incongruent with the characteristic features of SMEs. Therefore, it is recommended that these prerequisites be re-evaluated and revised to align with the characteristic features and structures of SMEs.

Table 2

Prerequisites for Digital Transformation in SMEs (Mittal et al., 2018)

Finance	Taking into Account the Financial Situation of SMEs
Technology Resource Availability	Considering the Expected Technological Resources from SMEs
Standards	The concept of standardization should be reconsidered within the context of SMEs.

Finance	Taking into Account the Financial Situation of SMEs
Organizational Culture	The structure of SMEs should be taken into account.
Employment Participant	Employee participation is pivotal for fostering digital maturity, ensuring the effective integration of digital technologies within organizations
Alliances	Alliances are vital for advancing Digital Maturity by promoting collaboration, knowledge exchange, and resource sharing among organizations.
Collaboration	SMEs, by their nature, are highly dependent on suppliers. This situation leads to a differentiation in the collaborative environment compared to large enterprises. Therefore, the concept of collaboration should be reevaluated in modeling for SMEs.

In their study, Baki and Serdar (2020) examined twenty-four sectoral and academic digital transformation maturity models. The study revealed that each model has its own unique criteria and dimensions. Upon reviewing these models, it is evident that many of them are applied within specific sectors. The research suggests that the textile and electronics industries are the most studied sectors within the scope of digital transformation maturity models. Baki and Serdar (2020) also investigated other studies in the literature that applied digital transformation maturity models, finding that these models are predominantly used by large-scale firms and that many maturity models overlook SMEs.

The study conducted a literature review and identified "IMPULS" and "A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises" as the most commonly used models. Baki and Serdar (2020) point out that among the existing models, two models, namely "IMPULS" and "A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises," are considered by the authors to be capable of assessing SMEs in terms of Industry 4.0 readiness and digital maturity.

Şener et al. (2021) systematically examined the strengths and weaknesses of 23 maturity models found in the literature. Based on the findings of the study, it was determined that the existing maturity models did not meet the specified criteria (scope, relevance to purpose, completeness of dimensions, clarity, understandability) in many aspects, and in this context, the creation of a more comprehensive maturity model is recommended. The study suggests that out of the 23 models examined, only two could be considered for evaluating the digital maturity level of SMEs. These models are "A Maturity Level-Based Assessment Tool to Enhance the Implementation of Industry 4.0 in SMEs" (Rauch et al., 2020) and "Three-Stage Maturity Model in SME's Towards Industry 4.0" (Ganzarain & Errasti, 2016). However, considering SMEs, it is emphasized that these two models also have shortcomings in meeting the needs of SMEs.

According to Barata and Cunha (2017), while existing digital transformation maturity models provide a good guidance tool at the initial stages of digital transformation, they have some shortcomings. These shortcomings are summarized in four points:

a) The models are not flexible enough to adapt to change.

b) They tend to focus more on defining problems rather than generating solutions.

c) They do not measure progress over time in sufficient detail.

d) Compared to social and organizational issues, they place too much emphasis on business processes.

On the other hand, the models are noted to not speak the language of SMEs and should be customized to be more focused on specific domains, especially for SMEs operating in traditional structures. Williams et al. (2022) conducted a systematic literature review to examine the current state of digital transformation maturity models and their applicability to SMEs. The study focused on analyzing the

capacities of SMEs based on existing literature studies, and the results obtained from these studies were tested using a semi-structured interview technique. According to the findings, the existing Digital Transformation Maturity Models lack terminology suitable for SMEs and do not fully conduct a gap analysis of the existing needs for SMEs. It is emphasized that these deficiencies result in the failure to achieve the ultimate goal of digital transformation maturity models, which is the preparation of a digital transformation roadmap. When examining the studies in Table 3, it is indicated that the inability of DTM models to develop a common terminology is attributed to the lack of a corporate identity structure among SMEs and their potential for internal differentiation.

Table 3

Studies Examining Digital Transformation Maturity Models from the SMEs Perspective

Study	The Number of Examined Models or Academic Reviews	Finding for SMEs
Barata & Cunha (2017)	-	There is a need for models that align with the traditional structures and characteristics of SMEs
Mittal et al., (2018)	15 models	While some models take SMEs into account, the common characteristics of these models may not have developed a sufficiently comprehensive perspective for SMEs.
Williams et al. (2019)	6 models	As models are produced considering large-scale enterprises, they may not be deemed sufficient for SMEs in certain aspects. However, in terms of dimensions, existing models can be inspiring in creating models suitable for SMEs.
Baki & Serdar, (2020)	24 models	The study examined models created on a sectoral basis. In this context, it is emphasized that the sectors where the most studies have been conducted in the field of DOM are electronics and textiles. When it comes to SMEs, it is noted that, except for two models, existing models do not fully meet the requirements.
Şener et al., (2021)	23 models	From the models examined in the study, only two were deemed suitable for SMEs, although deficiencies in certain areas are still emphasized.
Williams et al., (2022)	13 academic works	It is stated that DT Models do not have appropriate terminology for SMEs and fall short in conducting a specific needs analysis for SMEs.

Some studies suggest that existing models can be partially effective in preparing a digital transformation roadmap for SMEs (Baki & Serdar, 2020; Şener et al., 2021). According to the expressions in these studies, existing models possess motivating and partially guiding elements for determining the digital maturity of SMEs. For example, many dimensions found in these models may be applicable to SMEs, but the criteria used to explain these dimensions need to be redesigned specifically for SMEs. On the other hand, it is emphasized that many models may fall short in conducting analyses tailored to the needs of SMEs due to the lack of suitable terminology and needs analysis for SMEs (Mittal et al., 2018; Williams et al., 2019). In conclusion, while it does not seem possible to find a fully prominent digital transformation maturity model for SMEs in the literature, it can be said that some models may inspire and serve as examples for the creation of a new model specifically designed for SMEs.

Discussion and Conclusion

Considering the regional development, the positions and roles of SMEs (Small and Medium-sized Enterprises) in the country and regional economies are crucial. The contributions of SMEs to employment, the economy, and the industry through their complementary roles are emphasized by many researchers. On the other hand, when the general characteristics of SMEs are examined, despite having a less complex structure, factors such as financial constraints, deficiencies in accessing information and technology, and dependencies on external sources emerge as challenges for them in the digital transformation, as in many other areas. The fact that digital transformation is an inevitable process regardless of the size of businesses today becomes a significant source of competition and value creation pressure for SMEs. Given the challenges that SMEs face, digital transformation, which is already a complex process, needs to be approached in a more systematic and planned manner for SMEs. Digital Transformation Maturity Models, on the other hand, emerge as analytical tools designed to systematize this complex process for businesses (Kane et al., 2017). While the dimensions embedded in these models may be suitable for the structures of SMEs, the diverse interpretation of these dimensions in SMEs, their unique structures, and their ability to adopt different approaches from the management mindset in large enterprises suggest that DTM Models may be insufficient for SMEs. However, when existing models and related literature are examined, the point that researchers particularly emphasize is that there is not a model that is fully suitable for SMEs. It is concluded that many developed models are either suitable for only specific sectors or, although applicable to many sectors, can be efficiently used only by companies that are large enough. In this context, existing Digital Transformation Maturity Models fall short in terms of their contributions to the digital transformation of SMEs. As many researchers highlight, SMEs have unique characteristic features. The reality that existing models only cover the needs of large-scale firms results in SMEs not being able to fully benefit from Digital Transformation Maturity Models, which are seen as tools for SMEs in digital transformation. Therefore, there is a need for a DTM Model tailored to SMEs. Currently, businesses that have successfully undergone digital transformation have a competitive advantage, as they can create added value more rapidly through the active use of information technologies and demonstrate greater enthusiasm for innovative approaches. Addressing this deficiency is not only about addressing a specific gap for SMEs but can also be a crucial element in promoting progress and development at regional, national, and global levels.

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Chapter 6

Artificial Intelligence-Enabled Applications for Diagnosing and Treating Vascular Diseases: An Overview of Developments to Enhance CFD Applications

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Abstract

Vascular diseases remain a major cause of morbidity and mortality worldwide, necessitating early and precise diagnosis and treatment. Traditional methods often face limitations in efficiency, cost, and accuracy. Recent advancements in artificial intelligence (AI), particularly in machine learning, deep learning, and computer vision, have begun to transform the landscape of vascular disease management. When integrated with computational fluid dynamics (CFD), AI enables more accurate simulation of hemodynamics, accelerating diagnosis, treatment planning, and risk assessment. This study presents a comprehensive overview of AI-driven approaches in the diagnosis and treatment of vascular diseases, emphasizing the synergy between AI and CFD. It highlights key applications such as automated vessel segmentation, real-time blood flow prediction, aneurysm risk stratification, personalized treatment planning, and postoperative monitoring. AI techniques including convolutional neural networks, surrogate models, and reinforcement learning have enhanced the speed and precision of CFD simulations, offering clinicians improved tools for understanding complex hemodynamic conditions. Despite existing challenges in clinical integration and data quality, the continued evolution of AI-enabled CFD models is expected to play a pivotal role in personalized medicine, offering scalable and patient-specific solutions for vascular health management.

Keywords Vascular diseaeses · hemodynamics · computational fluid dynamics · artificial intelligence.

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Introduction

Vascular diseases, encompassing a wide range of conditions such as atherosclerosis, aneurysms, strokes and venous disorders, are among the leading causes of morbidity and mortality worldwide (Huang & van Gelder, 2002). Early diagnosis and precise management of these diseases are critical in reducing adverse health outcomes (Netala et al., 2024). However, conventional diagnostic methods and treatment approaches can be time-consuming, costly, and prone to human error. The advent of artificial intelligence (AI) has significantly transformed the landscape of vascular disease diagnosis and treatment, offering innovative solutions that promise more accurate, efficient, and personalized care. AI, particularly deep learning, machine learning, and computer vision, has shown substantial promise in the medical field, and its applications are being increasingly integrated into clinical workflows. This work provides a comprehensive summary of the current developments in AI-enabled applications for diagnosing and treating human vascular diseases. It also explores how these technologies are being harnessed to accelerate clinical applications and improve patient outcomes (Kissas et al., 2019).

Computational fluid dynamics (CFD) has long been a powerful tool in understanding fluid flow, and its application to vascular diseases has the potential to significantly enhance diagnosis and treatment planning. In the context of vascular diseases, CFD is used to simulate blood flow through arteries, veins, and other blood vessels, providing crucial insights into the underlying hemodynamics that drive conditions such as atherosclerosis, aneurysms, and arterial stenosis (Ong et al., 2020). However, while CFD is valuable, it is also computationally intensive and requires highly specialized knowledge to implement effectively in clinical settings. This is where (AI) comes into play, enabling the integration of CFD with data-driven models to accelerate diagnosis, enhance treatment planning, and ultimately improve patient outcomes (Liang et al., 2020).

AI has emerged as a transformative force in the field of medical diagnostics, particularly in the detection of diseases within human vessels. The complexity of vascular diseases, which include conditions like atherosclerosis, aneurysms, and vascular malformations, has made their diagnosis and management particularly challenging (Doost et al., 2016). However, AI-driven technologies are revolutionizing the way these conditions are detected, analyzed, and monitored, offering more accurate, efficient, and timely diagnoses (Taebi, 2022). Furthermore, machine learning algorithms contribute to the development of personalized treatment plans by extracting meaningful insights and predictions from large datasets. This provides a powerful tool for optimizing patients' health conditions and enhancing treatment processes (Liang et al., 2017).

AI applications in the management of vascular diseases are transforming the healthcare landscape by facilitating early detection, precise diagnosis, and tailored treatment through sophisticated analysis of medical imaging and patient information. These innovations enhance risk assessment, streamline clinical processes, and enable remote monitoring, ultimately resulting in improved patient outcomes and lower healthcare expenses. Furthermore, AI is poised to spearhead advancements in autonomous interventions, predictive maintenance of vascular implants, integration of cross-specialty care, and drug discovery, establishing itself as a fundamental element of future vascular healthcare.

This work provides a comprehensive overview of the current developments in AI-enabled applications that are accelerating the integration of CFD into clinical applications for diagnosing and treating human vascular diseases. We will explore the combination of AI and CFD, how these technologies complement each other, and the impact they are having on clinical practice. A variety of databases, including PubMed, IEEE Xplore, Scopus, and Web of Science, were searched using a combination of keywords such as "artificial intelligence," "vascular diseases," "computational fluid dynamics," "machine learning," "deep learning," and "diagnosis" or "treatment." The inclusion criteria were as follows: (1) peer-reviewed

articles published in English, (2) studies that specifically address AI-based methods applied to vascular diseases, and (3) articles that highlight or integrate CFD techniques. Exclusion criteria encompassed non-peer-reviewed content, editorial pieces, and studies lacking a clear methodological framework. The search strategy aimed to capture both foundational and recent advancements in the field to ensure a balanced and insightful review.

Table 1 summarizing different artificial intelligence applications for diagnosing and treating human vascular diseases.

Table 1
AI applications and impacts on vascular disease management

AI Application	*Description*	*Clinical Use*	*Impact on Vascular Disease Management*
AI for Vessel Segmentation	Deep learning models (e.g., CNNs) automate the segmentation of blood vessels from medical images (CT, MRI, Ultrasound).	Vessel geometry reconstruction for CFD simulations.	Reduces manual work, speeds up image processing, and increases accuracy.
AI-Enhanced CFD Simulations	AI optimizes CFD simulations by predicting blood flow dynamics based on patient data.	Blood flow modeling in arteries and veins to study disease progression.	Provides faster and more accurate simulations, reducing computational time.
Aneurysm Risk Prediction Using AI	Machine learning models predict the risk of aneurysm rupture based on size, shape, and blood flow patterns.	Risk assessment for abdominal and cerebral aneurysms.	Improves risk stratification and helps determine when surgical intervention is needed.
AI for Personalized Treatment Plans	AI analyzes patient data (genetics, history, imaging) to recommend personalized treatment strategies.	Selection of optimal medical, surgical, or interventional treatment for PAD, CAD, etc.	Tailors treatment to individual needs, improving outcomes and reducing adverse effects.
AI in Surgical Planning and Simulation	AI simulates the effects of various surgical procedures (e.g., stenting, bypass) on blood flow and vascular health.	Pre-operative planning for vascular surgery (e.g., stent placement).	Enhances surgical precision and decision-making, reducing complications.
Predictive Models for Disease Progression	AI analyzes longitudinal data to predict the progression of vascular diseases like atherosclerosis and PAD.	Long-term monitoring of disease and early intervention strategies.	Enables proactive management of chronic conditions, preventing severe complications.
AI for Monitoring	AI algorithms analyze imaging data (CT, MRI, Ultrasound) to detect vascular abnormalities such as aneurysms, stenosis, or plaque.	Diagnostic imaging interpretation and disease detection.	Provides quicker, more accurate diagnoses, and assists radiologists in routine clinical practice.

CNN: Convolutional neural network, CT: Computerized tomography, MRI: Magnetic resonance imaging

This table outlines how AI is being applied to accelerate the diagnosis and treatment of human vascular diseases, with a particular focus on improving CFD applications and integrating them into clinical workflows. The synergy between AI and CFD technologies is transforming how vascular diseases are diagnosed, treated, and monitored, leading to more personalized and efficient patient care.

Understanding CFD in Vascular Disease Diagnosis

CFD applications in vascular disease diagnosis focus on simulating blood flow in the human vasculature, offering insights into fluid dynamics, shear stress, and pressure gradients that are difficult to assess through traditional imaging methods alone. In conditions like atherosclerosis, the narrowing of arteries due to plaque buildup can significantly alter blood flow, potentially leading to heart attacks, strokes, or other vascular events. CFD allows for detailed analysis of these changes and can provide information about blood flow patterns, turbulent flow regions, and areas of high shear stress all of which are important indicators of disease progression (Gerrah et al., 2020).

However, CFD simulations are computationally demanding and can take hours or even days to perform using traditional methods. To address this challenge, AI-driven techniques have been integrated with CFD to reduce the time and computational resources required to generate high-quality, clinically relevant simulations. AI can automate certain processes, such as segmenting vessel geometry from medical images, predicting blood flow patterns based on limited data, and optimizing CFD simulations in real-time (Tesche et al., 2018).

Figure 1 shows the number of studies over the last 40 years involving AI-enabled CFD applications on blood flow prediction. As a result of the search in the Scopus database according to the TITLE-ABS-KEY (“CFD” and “Artificial Intelligence” and “Hemodynamics”) criteria, 1887 studies are obtained. The data shows a steady increase in the number of papers published annually. This reflects the growing interest and advancements in AI, ML, and CFD methods for predicting blood flow, which are becoming increasingly important in diagnoses of human vessel diseases.

Figure 1

Number of papers in AI for CFD to blood flow prediction per year (1983-2025)

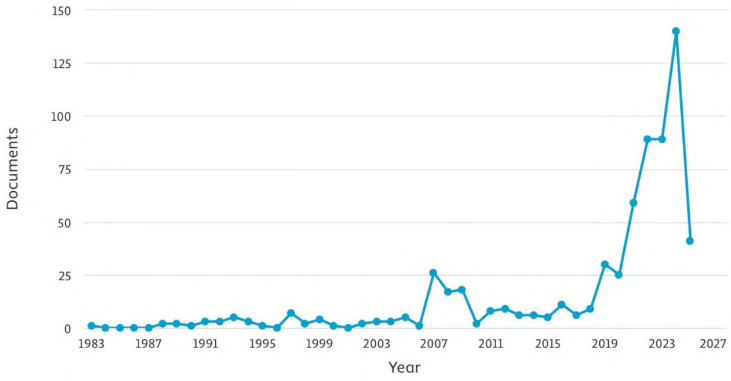
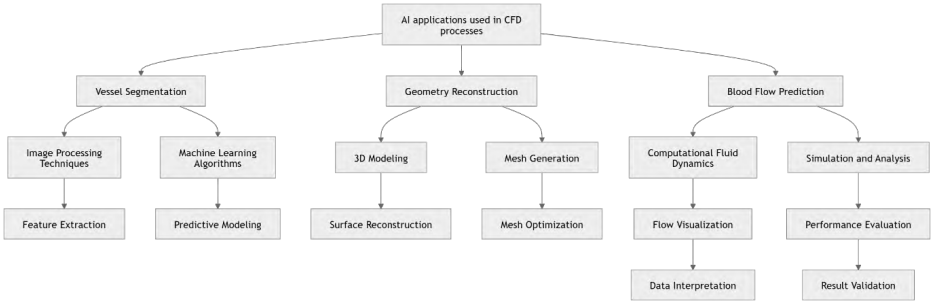


Figure 2 demonstrates the use of AI methods in CFD applications, focusing on blood flow analysis. It begins with Vessel Segmentation, where AI algorithms, particularly Deep Learning (DL) models, automatically identify and delineate blood vessels from medical imaging data such as CT or MRI scans. The next step is Geometry Reconstruction, where AI transforms the segmented data into accurate 3D models of the vascular system, enabling detailed fluid flow simulations. Finally, Blood Flow Prediction utilizes AI to model and predict key hemodynamic parameters like blood velocity, pressure, and shear stress

within the reconstructed vessel geometry. Together, these AI-driven methods improve the precision, speed, and personalization of CFD simulations, aiding in the diagnosis and treatment of cardiovascular conditions.

Figure 2

AI methods in CFD applications



AI-Driven Vessel Segmentation and Geometry Reconstruction

One of the most time-consuming steps in CFD simulations is the reconstruction of accurate 3D models of the vascular anatomy from medical images such as CT angiograms, MRI scans, or ultrasound images. Traditionally, this process involves manual segmentation, which is labor-intensive and prone to human error. AI, particularly DL techniques, has dramatically accelerated this process by automating vessel segmentation (Cebral et al., 2005).

• Deep Learning for Vessel Segmentation: AI models, especially CNNs, have shown remarkable accuracy in automatically segmenting vascular structures from medical imaging. These DL models are trained on large datasets of annotated vascular images, enabling them to identify and delineate complex vascular structures such as arteries, veins, and aneurysms. Once the vessels are segmented, they can be used to generate precise 3D models that serve as the foundation for CFD simulations (Su et al., 2021).

• Accelerating the Reconstruction Process: AI can also optimize the process of reconstructing 3D vessel geometries by filling in gaps or resolving ambiguities that may arise in low-resolution or noisy medical images. This reduces the time needed for image processing and ensures the accuracy of the input data for CFD simulations (Liang et al., 2017).

AI in Blood Flow Prediction and Optimization

One of the most challenging aspects of CFD simulations is predicting the behavior of blood flow through diseased vessels, especially in complex regions such as aneurysms or stenosed arteries (Luraghi et al., 2018). Traditional CFD methods require detailed input data, such as boundary conditions (e.g., blood pressure, flow rates), and the results can vary depending on the assumptions made during setup. AI models can be trained to predict blood flow patterns directly from patient-specific data, reducing the need for extensive CFD simulations and providing more immediate feedback to clinicians. These AI-driven approaches can optimize blood flow predictions by leveraging both CFD results and clinical data to enhance model accuracy (Li et al., 2021).

In CFD applications, predicting blood flow is a critical aspect of understanding vascular health, especially when assessing conditions such as arterial stenosis, aneurysms, and other cardiovascular diseases. AI methods play a pivotal role in enhancing the accuracy, efficiency, and customization of blood flow predictions. These AI-driven approaches are transforming how fluid dynamics are modeled

in the human vascular system by providing tools that allow for more precise, patient-specific simulations AI methods used to estimate the hemodynamic properties of blood are listed below, respectively (Liu et al., 2019).

- Machine Learning Models: Traditional CFD methods rely on solving complex fluid dynamics equations, which can be computationally expensive and time-consuming, particularly when simulating blood flow in detailed geometries. Machine learning (ML) models have emerged as an effective way to accelerate and simplify these simulations. Algorithms such as support vector machines (SVM), random forests, and k-nearest neighbors (k-NN) are employed to predict various hemodynamic parameters like blood velocity, pressure, and shear stress based on patient-specific vascular geometries. These models are trained on large datasets that include simulated blood flow values and corresponding vessel characteristics, enabling the AI to learn complex relationships between geometry and fluid behavior.
- Deep Learning for Complex Fluid Dynamics: DL models, particularly CNNs and recurrent neural networks (RNNs), are widely used in blood flow prediction due to their ability to learn from vast amounts of data and make predictions without explicitly solving fluid dynamics equations. CNNs can be used to analyze 3D medical images or reconstructed geometries, identifying patterns in the vascular structure that are crucial for simulating blood flow. RNNs, especially long short-term memory (LSTM) networks, are useful when modeling time-dependent fluid behavior, such as the pulsatile nature of blood flow. These networks excel at capturing sequential dependencies in the data, allowing for more accurate predictions of how blood flow evolves over time in the cardiovascular system.
- Surrogate Models: Surrogate models, often built using ML techniques, serve as approximations of more computationally intensive CFD models. These AI-driven surrogate models can provide fast, accurate predictions of blood flow in complex vascular networks. By training the surrogate model on CFD results from a smaller set of simulations, it can generalize the flow behavior to new, unseen geometries, making it highly useful in clinical applications where quick assessments are necessary. Surrogate models have proven effective for real-time blood flow predictions, providing valuable insights into hemodynamic conditions like wall shear stress or flow velocities without the need for repeated, expensive CFD simulations.
- Reinforcement Learning for Optimizing Blood Flow: Reinforcement learning (RL), a type of machine learning where an agent learns by interacting with an environment to maximize rewards, is also being explored for blood flow prediction. In CFD applications, RL can be used to optimize surgical procedures or interventions by simulating the effect of different strategies on blood flow. For example, RL algorithms can help optimize stent placement in arteries by predicting how various stent designs or placements will impact blood flow, potentially improving patient outcomes.
- Hybrid AI-CFD Models: Another promising approach in blood flow prediction is the integration of AI with traditional CFD solvers. In this hybrid approach, ML algorithms are used to enhance the CFD models, speeding up the simulation process or improving accuracy by identifying relevant features and conditions that traditional models might miss. For example, ML can assist in determining boundary conditions or selecting optimal mesh refinements, which are critical for accurate flow simulations. Hybrid AI-CFD models can be particularly beneficial in personalized medicine, where each patient's unique vascular geometry requires custom simulations.
- Physics-Informed Neural Networks (PINNs) are a class of DL models that incorporate physical laws, typically represented by partial differential equations (PDEs), directly into the training process. Unlike traditional neural networks that rely solely on data, PINNs use the governing

equations of a system as part of the loss function, enabling them to learn solutions that respect the underlying physics even with limited or noisy data. This makes PINNs particularly valuable for solving complex scientific and engineering problems, including fluid dynamics, biomechanics, and vascular flow modeling, where data may be sparse but physical laws are well-understood. Their ability to combine data-driven learning with domain knowledge opens new frontiers in simulation, prediction, and control of physical systems.

The Advantages of AI in Blood Flow Prediction are vast, enabling significant improvements in how blood flow dynamics are modeled and understood in medical application. Table 2 organizes the key advantages and provides a brief description of how AI methods improve blood flow prediction in CFD applications.

Table 2

The advantages of AI in blood flow prediction

Advantage	Description
Improved Accuracy	AI methods excel at capturing complex, non-linear relationships between vascular geometry and blood flow, resulting in more accurate predictions than traditional CFD models.
Computational Efficiency	AI-driven methods significantly reduce the computational time and resources required for blood flow prediction, making them ideal for time-sensitive clinical environments.
Real-time Analysis	AI enables real-time blood flow analysis, critical during surgeries for constant monitoring and immediate feedback to medical professionals.
Robustness to Variability	AI techniques handle variability in patient anatomy and blood flow conditions, allowing for accurate predictions across diverse patient demographics.
Personalization	AI provides personalized simulations based on patient-specific data, enabling clinicians to make informed decisions about treatment options.

While AI methods for blood flow prediction show great promise, challenges remain. The quality and quantity of the data used to train AI models are crucial; inaccurate or insufficient data can lead to poor predictions. Additionally, the interpretability of AI models is an ongoing issue, as many DL models are seen as "black boxes," making it difficult for clinicians to understand how predictions are made. As AI continues to evolve, efforts to improve model transparency and ensure that these methods are clinically valid will be essential.

AI in Aneurysm Risk Stratification and Management

Aneurysms, particularly in the abdominal aorta and cerebral vessels, present a major risk for life-threatening complications, including ruptures (Can & Du, 2016). CFD simulations are critical for understanding the hemodynamic forces at play in aneurysms, as regions of high shear stress and turbulence may accelerate aneurysm growth. However, traditional methods of calculating the risk of rupture rely heavily on geometric measurements and static assumptions about blood flow (Camasão & Mantovani, 2021).

AI has the potential to revolutionize aneurysm risk stratification by integrating CFD simulations with clinical data and patient history. ML models can be trained to assess the risk of rupture based on factors such as aneurysm size, shape, growth rate, and flow characteristics. AI can provide more personalized predictions of rupture risk, enabling clinicians to make better-informed decisions about when to intervene with surgery or other treatments (Li et al., 2023).

• AI-Driven Aneurysm Monitoring: AI models can track aneurysm progression over time by analyzing regular imaging data and hemodynamic simulations. By identifying changes in blood flow patterns, AI systems can detect early signs of increased rupture risk and alert clinicians to take appropriate action (Rajpurkar et al., 2022).

AI for Optimizing Surgical Planning and Postoperative Care

AI can also enhance the surgical treatment of vascular diseases by integrating CFD simulations with surgical planning tools. For example, in the case of stent placement for stenotic arteries, AI can help predict the optimal stent size, location, and deployment method based on patient-specific CFD simulations (Li et al., 2024).

• Surgical Simulation and Planning: AI-driven surgical planning tools can simulate the effects of various interventions (e.g., stenting, bypass surgery) on blood flow dynamics, predicting how each procedure will alter the flow and pressure within the vessel. This allows surgeons to select the best approach for individual patients and minimize complications (Albertini et al., 2024).

• Postoperative Monitoring: After vascular interventions, AI can aid in postoperative care by continuously monitoring changes in blood flow and detecting signs of complications such as restenosis or stent failure. By combining real-time patient data with CFD simulations, AI systems can track the success of surgical interventions and provide timely alerts to healthcare providers if any issues arise (Mohammadi et al., 2025).

Discussion

The integration of artificial intelligence in the diagnosis and treatment of vascular diseases represents a major advancement, particularly when paired with CFD modeling. This review highlights the growing body of research that employs ML and DL techniques to automate the analysis of images, enhance hemodynamic simulations, and support clinical decision-making processes. AI-based tools have demonstrated exceptional capabilities in precisely segmenting vascular structures, predicting blood flow behavior, and identifying pathophysiological patterns with a speed and accuracy that surpass traditional methods.

However, several challenges and limitations remain. A major hurdle is the absence of standardized datasets and benchmarks, which complicates the ability to make direct comparisons between different studies. Additionally, many AI models, especially those based on deep learning, necessitate substantial amounts of annotated data, which are often challenging to acquire in clinical environments due to privacy issues and the labor-intensive nature of the labeling process. Furthermore, the "black-box" characteristic of numerous DL models raises concerns regarding their interpretability and the level of trust clinicians can place in them, particularly in critical situations such as surgical planning or disease prognosis.

For AI-driven CFD applications to move from the realm of research into standard clinical practice for diagnosing and treating vascular diseases, it is essential to address several key factors beyond mere technical efficacy. These include building trust, ensuring usability, and achieving seamless integration with current medical workflows. Clinicians are more inclined to embrace AI tools that provide interpretability and transparency, such as confidence scores, explainable features, or visual aids—like flow maps or anatomical overlays—that augment rather than supplant their clinical decision-making. Effective incorporation into hospital systems is crucial for reducing disruptions and enhancing clinical utility, with promising examples including AI-assisted segmentation and real-time, machine learning-accelerated CFD simulations. Additionally, ethical issues such as data privacy, informed consent,

algorithmic bias, and health equity must be prioritized. AI systems developed using non-representative datasets may exacerbate existing disparities; therefore, it is vital to ensure transparency regarding data sources, validate algorithms on diverse populations, and implement continuous monitoring to uphold fairness. Compliance with regulations such as HIPAA and GDPR is critical for gaining patient trust, especially as AI models undergo continuous learning. Furthermore, obtaining regulatory approval from organizations like the FDA or EMA necessitates thorough testing to confirm safety and reliability in clinical environments. Ultimately, the successful implementation of AI-CFD applications will hinge on harmonizing innovation with ethical accountability and practical requirements, ensuring that these technologies contribute to improved patient outcomes in a trustworthy and sustainable manner.

Numerous artificial intelligence techniques have been utilized in the diagnosis of vascular diseases and the improvement of CFD models; however, their effectiveness and appropriateness can differ markedly based on the specific context of application. Traditional ML techniques, including SVMs and random forests, provide high levels of interpretability and require relatively small datasets, making them ideal for initial screening processes. Nevertheless, these methods often fall short in complex pattern recognition tasks when compared to deep learning models. For example, CNNs have shown enhanced accuracy in medical image segmentation and classification due to their capability to automatically identify hierarchical features. In contrast, RNNs and LSTM networks excel in analyzing time-series data, such as monitoring hemodynamic changes over time. Emerging hybrid models that integrate physics-based CFD simulations with data-driven AI algorithms present a promising solution, balancing accuracy with a certain level of explainability. A thorough comparison indicates that while no single approach is definitively superior, the selection of AI methodologies should be informed by clinical goals, data availability, and the necessity for model interpretability.

A significant finding from this work is the ability of artificial intelligence to alleviate the computational demands associated with CFD simulations. Techniques such as surrogate modeling, reduced-order modeling, and neural networks designed to replicate CFD outputs can drastically reduce simulation durations, facilitating near-real-time analysis within clinical settings. These advancements hold the potential to enhance point-of-care applications, including personalized treatment strategies tailored to individual patient hemodynamics.

Conclusion

Despite the remarkable potential of AI-enabled CFD applications, several challenges remain. One of the primary hurdles is the integration of AI and CFD into clinical practice. These technologies require significant computational resources, and clinical workflows need to be adapted to incorporate AI-driven tools effectively. Additionally, training healthcare providers to interpret AI-assisted CFD results and incorporate them into their decision-making processes is crucial for successful implementation. Data quality and accessibility also pose challenges. AI models require high-quality, annotated datasets for training, and acquiring such datasets for complex vascular diseases is often difficult. Standardization of imaging protocols and data formats is necessary to ensure that AI and CFD applications can be used reliably across diverse healthcare settings.

Looking to the future, the combination of AI and CFD will continue to evolve, with innovations in ML algorithms, improved imaging technologies, and more accessible computational resources. As these technologies mature, we can expect to see widespread adoption of AI-driven CFD tools in the diagnosis, treatment planning, and management of vascular diseases. The integration of artificial intelligence with computational fluid dynamics represents a significant breakthrough in the diagnosis and treatment of vascular diseases. AI is accelerating the use of CFD by automating vessel segmentation, predicting blood flow, optimizing surgical planning, and enhancing patient-specific simulations. These advances

are transforming clinical practice, providing clinicians with more accurate and timely insights that can improve decision-making and patient outcomes. As AI and CFD technologies continue to develop, they will play an increasingly critical role in advancing personalized medicine for vascular disease management, enabling more effective and tailored treatments for patients worldwide.

In conclusion, the integration of artificial intelligence with computational fluid dynamics represents not just a technological enhancement but a transformative shift in vascular healthcare. This collaboration simplifies traditionally labor-intensive tasks and improves the accuracy of hemodynamic modeling, providing a robust set of tools for clinicians and researchers alike. It effectively connects intricate data analysis with practical clinical applications, enabling real-time assessments tailored to individual patients that were once beyond reach. Moreover, as AI continues to evolve through expanding datasets and advancements in CFD methodologies, the reciprocal relationship between clinical results and simulation precision will become more robust, promoting a more responsive and intelligent healthcare system. This evolution will not only diminish diagnostic ambiguities but also facilitate predictive modeling, early intervention tactics, and preventive care measures. Ultimately, the fusion of AI and CFD signals a future in which vascular treatments are not only more effective but also highly personalized, marking the dawn of a new era in precision medicine with a significant global influence.

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Chapter 7

Determination of Molecular Pathways and Gene Ontology of Genes Associated with Thromboangitis Obliterans Disease

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Abstract

Thromboangiitis obliterans (TAO), also called Buerger's disease (BD), is a non-atherosclerotic, inflammatory vascular disease that primarily affects small or medium-sized arteries and veins in the extremities.

The aim of the study is to determine the molecular pathways in which genes associated with Thromboangitis Obliterans disease and to reveal their biological processes and molecular functions by gene ontology (GO) analysis.

According to the results in the GeneCards Suite database over the MalaCards Human Diseases database, it was determined that Thromboangitis Obliterans disease is associated with cytokine signaling in the immune system, PI3K-Akt signaling pathway, blood-brain barrier and immune cell transmigration: VCAM-1/CD106 signaling, development VEGF signaling via VEGFR2- generic cascades, CCL18 signaling pathway, photodynamic therapy-induced NF-kB survival signaling, HIF1Alpha pathway, pluripotent stem cell differentiation pathway, Thromboxan A2 receptor signaling, interleukin-4 and interleukin-13 signaling, development leptin signaling via JAK/STAT and MAPK cascades.

Genes associated with TAO disease in the MalaCards Human Diseases database APOH, CD34, CRP, VCAM1, VEGFA, ICAM1, EDN1, CSF3, F2, HGF, PROM1, FGF2, NOS3, SERPINC1 were detected. 14 genes obtained from the MalaCards Human Diseases database were included in the study for gene ontology analysis via the STRING database. Accordingly, possible interactions between 14 genes were determined through STRING and network enrichment was performed (avg. local clustering coefficient: 0.866, PPI enrichment p-value: < 1.0e-16).

A significant enrichment by Gene Ontology enrichment analysis was detected in a subset of genes involved in biological processes including membrane-to-membrane insertion, regulation of systemic arterial blood pressure by endothelin, paracrine signaling, negative regulation of smooth muscle cell apoptotic process, vascular wound healing. The assay for molecular function determined enrichment of a subset of genes in chemoattractant activity, growth factor activity, heparin binding, sulfur compound binding, growth factor receptor binding. We believe that identifying the molecular pathways that contribute to the development of TAO may lead to new molecular therapies that can restore impaired immunological homeostasis during disease. Some individuals may have a genetic predisposition to TAO disease. In line with the results we obtained, it was observed that it is especially involved in the immune system-related pathways. Therefore, it seems likely that TAO disease is an autoimmune disease.

Keywords Thromboangiitis obliterans · buerger's disease · molecular pathways · gene ontology · genes

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Introduction

Thromboangiitis obliterans (TAO), also known as Buerger's disease (BD), is a non-atherosclerotic, inflammatory vascular disorder. It affects primarily small or medium sized arteries and veins in the extremities. An important characteristic of TAO is the presence of an inflammatory thrombus in the affected vessels (Deng et al., 2021). The specificity of Buerger's disease lies in peripheral ischemia of an inflammatory nature with a self-limiting course, meaning that diagnostic criteria should be discussed from a clinical perspective. It has been suggested that thromboangiitis obliterans can be diagnosed using several criteria (Arkkila, 2006).

Diagnostic criteria of Shionoya (1998)

• smoking history;

• onset before the age of 50 years;

• infrapopliteal arterial occlusions;

• the arm is involved or the phlebitis migrans is present;

•other than smoking, there are no atherosclerotic risk factors (Arkkila, 2006).

Diagnostic criteria of Olin (2000)

• age under 45 years;

• current or recent history of tobacco use;

• symptoms such as claudication, pain during rest, gangrenous ulcers or non-invasive vascular testing suggest distal-extremity ischemia;

• diabetes mellitus, hypercoagulable states, and autoimmune diseases are excluded;

• a proximal source of emboli should be excluded with echocardiography or arteriography;

• clinically involved and non-involved limbs show consistent arteriographic findings (Arkkila, 2006).

The following is a list of clinical symptoms of BD: (Frost-Rude et al., 2000)

• During activity or rest, the hands and feet may experience pain or tenderness. Rest pain occurs earlier in the disease than in atherosclerosis. Pain typically occurs at the top of the foot, toes, or big toes.

• The hands and feet display changes in skin. The hands and feet may appear white, red, or blue. Ulcerations may occur on the fingertips.

• Temperature changes or a decrease in warmth are felt in the hands and feet. The hands and feet may experience coldness and numbness, followed by a burning sensation in the extremities as the temperature rises. Exposure to a cold or emotional distress may worsen the symptoms (Frost-Rude et al., 2000).

Young patients with distal extremity ischemia, rest discomfort, ulceration, or gangrene should be evaluated for BD. Patient history suggests the diagnosis. Compared to atherosclerosis, claudication is rare but usually includes the instep owing to the distal spread of occlusive disease. Upper extremity involvement is more common than atherosclerosis, and the most common clinical presentations are ischemic rest discomfort and forefoot ulcers. On average, 50% of patients have isolated lower extremity involvement, 30% to 40% have both lower and upper extremity ischemia, and 10% have just upper extremity symptoms. Raynaud's syndrome, or digital ischemia in the upper extremities, distinguishes it from atherosclerosis. Surface thrombophlebitis, which occurs in 40% to 50% of BD patients, is another clinical characteristic (Mills, 2003).

There are several validated treatments in the TAO involving prostaglandins, including intravenous iloprost. There is evidence of its effectiveness, including improvement of symptoms and better resolu-

tion of distal extremity trophic changes, as well as a reduction in amputations (Verdasca et al., 2018). Endothelin-1 may cause peripheral arterial occlusive disease by causing vascular damage. It has been shown that bosentan (endothelin-1 receptor antagonist) has anti-inflammatory, antifibrotic, and selective vasodilatory properties that reduce ischaemic ulcers caused by microvascular damage (Verdasca et al., 2018).

The stabilization of ischemia may be influenced by neovascularization and arteriogenesis. Many bone marrow cells have been shown to differentiate into one or more vascular bed cellular components, as evidenced by experimental studies. Thus, these cells can integrate directly into the vessel wall of newly formed or remodeled vessels, thereby accelerating neovascularization (Cacione et al., 2018). Neovascularization may be facilitated not only by the direct incorporation of endothelial progenitor cells, but also by their paracrine actions (the production of angiogenic cytokines, growth factors, and chemokines) that promote arteriogenesis and inhibit apoptosis in smooth muscle and endothelial cells. According to Kalka's experimental study, transplanting culture-expanded endothelial progenitor cells into an animal model of limb ischemia resulted in improved neovascularization, improved blood flow, and reduced limb necrosis by 50% in comparison to controls (Cacione et al., 2018). It differs from other forms of vasculitis in two important ways: it lacks autoantibodies, and it shows normal serological markers of inflammation. Smokers with distal artery disease are generally diagnosed based on distal artery disease after excluding other illnesses (Manfredini et al., 2004).

The immune system appears to be a crucial contributor to TAO etiology. Despite this, there is a lack of knowledge about immunological aspects involved in the progression and evolution of vascular tissue inflammation. Observation of antigenic antigens in tobacco may lead to TAO being an autoimmune disorder with antibodies directed towards the endothelium of vessels (Vijayakumar et al., 2013). There are numerous antibodies present in patients, including antinuclear, anti-elastin, anti-collagen I and III, antinicotine antibodies. The presence of IgG, IgC3, IgC4 deposits in their blood vessels also supports the theory of an immune characteristic to TAO (Vijayakumar et al., 2013). A strong correlation exists between heavy tobacco use and the onset and progression of the disease. The peripheral vasculature exhibits impaired endothelium-dependent vasorelaxation and increased cellular sensitivity to types I and III collagen. Further, TAO patients are found to have increased expression of intercellular adhesion molecule-1 (ICAM-1), vascular adhesion molecule-1 (VCAM-1), and E-selectin in their endothelium, suggesting that angiogenesis may play a role in the persistence of the inflammatory process. (Manfredini et al.,2004). There is an activation of endothelial cells in TAO, tissue-infiltrating inflammatory cells secrete TNF-α, endothelial cells express ICAM-1, VCAM-1, and E-selectin, and leukocytes adhesion is enhanced (Vijayakumar et al., 2013).

BD, in contrast to atherosclerotic peripheral arterial disease (PAD), causes nonatherosclerotic endarteritis that affects both arteries and veins. According to the pathology of BD, there are three distinct phases. The most diagnostic phase is the acute phase, in which a hypercellular inflammatory infiltrate accumulates within the vessels. A local prothrombotic state is triggered by vascular inflammation, leading to vaso-occlusion and subsequent microabscess formation. An acute granulomatous inflammation occurs, reorganizing and recanalizing the thrombus. A chronic thrombus develops vascular fibrosis, leaving a stenotic arterial lumen that mimics atherosclerosis lesions clinically (Ribieras et al., 2022).

The incidence of TAO is more common among men (male-to-female ratio, 3:1), but its prevalence is rising among women, which is attributed to the prevalence of smoking among women. This group of patients exhibits an increased prevalence of HLA-A9, HLA-A54, and HLA-B5, indicating a genetic predisposition (Jorge et al., 2011). Researchers also explored the hypothesis that infectious microorganisms contribute to disease pathophysiology. An increased prevalence of hepatitis B infection was recognised (Jorge et al., 2011). There may be a role for prothrombotic gene deletions in this disease due to both

genetic and thrombotic events. TAO studies detected prothrombotic genes significantly. Fibrinolysis is mediated by fibrinogen, which is synthesized in the liver and circulated in plasma and other extracellular fluids. Two regulatory enzymes that modulate plasminogen to plasmin are urokinase-type plasminogen activator (uPA) and tissue-type plasminogen activator (tPA). A major fibrinolytic inhibitor, PAI-1, blocks fibrinolysis. There is a polymorphism in the PAI-1 gene called a deletion/insertion of G base (5G/4G) in codon −675, which determines the expression of PAI-1 (Manduz et al., 2010). According to recent studies, TAO is an autoimmune disease, however, a lack of sufficient evidence makes it difficult to explain all of the immune disorder processes involved in TAO immunopathogenesis. Immune complexes (anti-endothelial cell antibodies and anti-neutrophil antibodies) were found to be significantly higher in serum from TAO patients compared with healthy individuals (Sun et al., 2017).

An immunocytochemical study suggests that BD represents immune-mediated arteritis because of the accumulation of immunoglobulins and complement factors. An immune response towards the endothelium has been confirmed by the presence of anti-endothelial antibodies. The immune system has been implicated in the development of TAO based on these findings (Shapouri-Moghaddam et al., 2019). There is evidence that chronic bacterial infections, such as oral periodontitis, may play a role in the pathogenesis of TAO. In addition, polymorphisms in genes linked to infectious immunity could play a role in the development of TAO. The Toll-like receptor 1 (TLR1) haplotype was correlated significantly with TAO (Koizumi et al., 2019). Rare vascular disorders include Takayasu arteritis (TA) and BD. There is no clear explanation for their etiology or pathogenesis, but several studies have suggested they are related to innate immunity. Toll-like receptors (TLRs) are crucial for detecting molecular patterns associated with pathogens and triggering adaptive immune responses. Many molecules serve as their ligands, including lipopolysaccharide, lipopeptides, bacterial DNA, and double- and single-stranded virus RNA. Among the adaptor proteins involved in downstream TLR signaling are MyD88 (myeloid differentiation primary response protein 88), MyD88-adaptor-like, adaptor protein containing TIR domain that induces IFNb, TRIF-related adaptor molecule, and sterile α- and armadillo-motif proteins (Chen et al., 2011). It is important for innate immunity in TLRs to activate the MyD88-dependent pathway (Sun et al., 2017).

According to Chen et al., the single nucleotide polymorphism (SNP) rs7744 in the MyD88 gene 30-untranslated region is significantly lower in patients with TAO than in healthy controls. There was no significant difference between the TA group and the healthy group (p = .011) on the GG genotype frequency in patients with TAO, which suggested that research should be conducted to determine how mutations affect the TLR signaling pathway and how they relate to TAO (Sun et al., 2017). On the surface of endothelial and epithelial cells, angiotensin-converting enzyme (ACE) is a zinc metalloprotease. Angiotensin I is a decapeptide converted by ACE into angiotensin II, an active octapeptide. This powerful vasoconstrictor is angiotensin II. ACE plays a crucial role in angiotensin II synthesis. A powerful vasoconstrictor, angiotensin II acts on the inflammatory process as well as the reninangiotensin system (Ozen et al., 2012). Ozen et al. (2012) found statistically significant differences between the patient and control groups in terms of age, smoking and ACE I/D gene polymorphisms, depending on their selection criteria (Olin's criteria). In addition to the effects of ACE on the cardiovascular system, the presence of ACE I/D polymorphism provides an interesting difference between the two groups that should not be overlooked (Ozen et al., 2012).

The aim of the study is to determine the molecular pathways in which genes associated with Thromboangitis Obliterans disease and to reveal their biological processes and molecular functions by gene ontology (GO) analysis.

Materials and Methods

Identification of Clinical Information about the Disease via the Orphanet Database

In this study, firstly, clinical information about TAO was searched through the Orphanet database. Information on "Epidemiology, Clinical Description, Etiology, Diagnostic Methods, Differential Diagnosis, Management and Treatment, Prognosis" was obtained in summary form through the Orphanet database.

Selection of TAO-Related Genes via the MalaCards Human Diseases Database

MalaCards is an integrated database of human diseases and annotations, modeled on the architecture and richness of the popular GeneCards human genes database.

In this study, 14 genes associated with TAO were identified through the MalaCards Human Diseases database. These genes were determined as [(Apolipoprotein H (APOH), CD34 Molecule (CD34), C-Reactive Protein (CRP), Vascular Cell Adhesion Molecule 1 (VCAM1), Vascular Endothelial Growth Factor A (VEGFA), Intercellular Adhesion Molecule 1 (ICAM1), Endothelin 1 (EDN1), Colony Stimulating Factor 3 (CSF3), Coagulation Factor II, Thrombin (F2), Hepatocyte Growth Factor (HGF), Prominin 1 (PROM1), Fibroblast Growth Factor 2 (FGF2), Nitric Oxide Synthase 3 (NOS3), Serpin Family C Member 1 (SERPINC1)].

Identifying TAO-Related Pathways Through the GeneCards Suite Database

TAO disease has been found to be associated with cytokine signaling in the immune system, PI3K-Akt signaling pathway, blood-brain barrier and immune cell transmigration: VCAM-1/CD106 signaling, development VEGF signaling via VEGFR2-generic cascades, CCL18 signaling pathway, photodynamic therapy-induced NF-kB survival signaling, HIF1Alpha pathway, pluripotent stem cell differentiation pathway, Thromboxan A2 receptor signaling, interleukin-4 and interleukin-13 signaling, development leptin signaling via JAK/STAT and MAPK cascades.

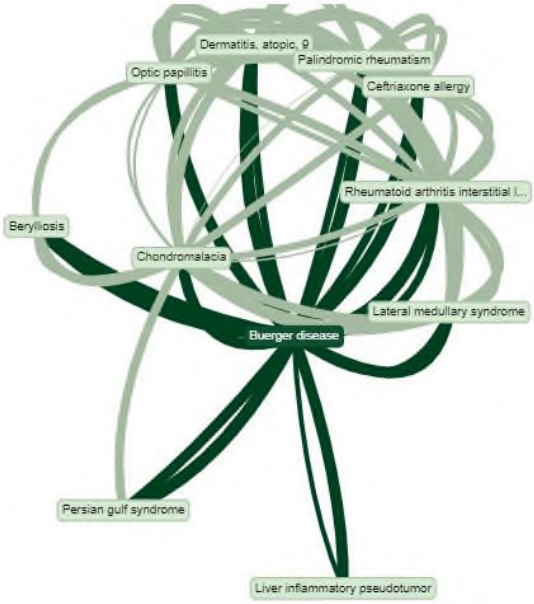
Gene Ontology (GO) Analysis of Genes via the STRING Database

String v11.5 analysis was used to create gene-gene and network interactions. Combined scores > 0.4 were chosen as significant. Since the combined score was found to be above 0.4 in all 14 genes, it was concluded that the link between genes was significant from node-node interactions.

Results and Discussion

The Phenotypic Disease Network via the MalaCards Human Disease Database identified comorbidity associations with TAO. It was observed that it was defined as essential hypertension and peripheral vascular disease. Then, the 10 most important known diseases related to TAO were determined and displayed as a graphical network (Figure 1). According to the results, the following diseases were detected: berylliosis, persian gulf syndrome, dermatitis atopic 9, rheumatoid arthritis, interstitial lung disease, palindromic rheumatism, optic papillitis, ceftriaxone allergy, lateral medullary syndrome, liver inflammatory pseudotumor, chondromalacia.

Figure 1
Graphical network of the top 10 diseases related to TAO



The GeneCards Suite database identified TAO-related pathways and genes. Eight pathways with high score values were found (Table 1).

Table 1
TAO-related pathways and genes

SuperPathway	Score	Related Genes
Innate Immune System	13.58	HLA-DPB1, F2, HLA-DRB1, ICAM1, CD34, CD14, CRP, VCAM1, MYD88
Class I MHC mediated antigen processing and presentation	12.93	ICAM1, MYD88, HLA-DRB1, VCAM1, CD34, CD14, HLA-DPB1
Immunoregulatory interactions between a Lymphoid and a non-Lymphoid cell	11.73	ICAM1, CD34, VCAM1
Mesenchymal Stem Cells and Lineage-specific Markers	11.48	CD34, CD14, VCAM1
Cytokine production by Th17 cells in CF	11.40	CD14, ICAM1, MYD88
miRNA role in immune response in sepsis	10.92	MYD88, VCAM1, ICAM1
LDL Oxidation in Atherogenesis	10.61	VCAM1, ICAM1
IL1 and megakaryocytes in obesity	10.18	ICAM1, MYD88, F2

Then, using the GeneCards Suite database, GO terms revealed cellular components (Table 2) and biological processes (Table 3).

Table 2
Cellular components related to TAO and the top affiliating genes

Name	GO ID	Score	Top Affiliating Genes
extracellular space	GO:0005615	10.13	VCAM1, PON1, MIR223, ICAM1, HLA-DRB1, F2
cell surface	GO:0009986	9.8	VCAM1, MYD88, ICAM1, HLA-DRB1, HLA-DPB1, CD34
external side of plasma membrane	GO:0009897	9.47	F2, GSR, HLA-DRB1, ICAM1, VCAM1, CD34

In our study, VCAM1, PON1, MIR223, ICAM1, HLA-DRB1, and F2 genes (score: 10.13), which are located in the extracellular space, were determined to be the best associated genes in cellular components related to TAO.

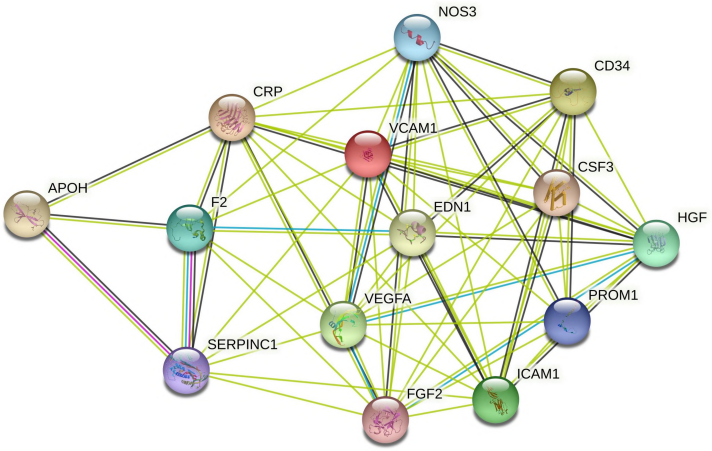
Table 3
Biological processes related to TAO and the top affiliating genes

Name	GO ID	Score	Top Affiliating Genes
inflammatory response	GO:0006954	10.01	CD14, CRP, MIR223, MYD88, VCAM1
response to lipopolysaccharide	GO:0032496	9.73	CD14, EDN1, MYD88, VCAM1
negative regulation of smooth muscle cell apoptotic process	GO:0034392	9.67	APOH, EDN1
regulation of blood coagulation	GO:0030193	9.61	APOH, F2
glomerular endothelium development	GO:0072011	9.46	CD34, EDN1
antigen processing and presentation of peptide or polysaccharide antigen via MHC class II	GO:0002504	9.32	HLA-DPB1, HLA-DRB1
membrane to membrane docking	GO:0022614	9.26	ICAM1, VCAM1
positive regulation of odontogenesis	GO:0042482	8.92	CD34, EDN1

Likewise, the most relevant genes, CD14, CRP, MIR223, MYD88, and VCAM1, which are involved in the inflammatory response in TAO-related biological processes (Score: 10.01), were detected.

14 genes obtained from the MalaCards Human Diseases database were included in the study for gene ontology analysis via the STRING database. Accordingly, possible interactions between 14 genes were determined through STRING and network enrichment was performed (avg. local clustering coefficient: 0.866, PPI enrichment p-value: <1.0e-16) (Figure 2).

Figure 2
Detection of interactions between 14 different genes expressed in patients with Thromboangitis Obliterans (String v11.5)



A significant enrichment by Gene Ontology enrichment analysis was detected in a subset of genes involved in biological processes including membrane-to-membrane insertion (GO:0022614), regulation of systemic arterial blood pressure by endothelin (GO:0003100), paracrine signaling (GO:0038001), negative regulation of smooth muscle cell apoptotic process (GO:0034392), vascular wound healing (GO:0061042). The assay for molecular function determined enrichment of a subset of genes in chemoattractant activity (GO:0042056), growth factor activity (GO:0008083), heparin binding (GO:0008201), sulfur compound binding (GO:1901681), growth factor receptor binding (GO:0070851). Data obtained from the Reactome pathway, we found that TAO, especially interleukin-4 and interleukin-13 signaling pathway (HSA-6785807) (false discovery rate: 2.34e-05) can play an important role on TAO.

A long-term study of multifunctional genes and diseases within the human genome can be extremely rewarding and helpful to other branches of science. The term multifunctional gene refers to human genes that have more than one function within a cell. Several studies have shown that these genes are more likely to contribute to disease. In order to discover new drugs and therapies, it is important to study these multifunctional genes and learn more about the multifunctional properties of genes (Al-Mubaid et al., 2019). We believe that identifying the molecular pathways that contribute to the development of TAO may lead to new molecular therapies that can restore impaired immunological homeostasis during disease. It may be possible to reveal the functions of the genes involved in these molecular pathways, to prevent the pathogenesis of the disease, and to screen smokers who are susceptible to TAO earlier.

The most prevalent areas affected by TAO, a segmental inflammatory condition that is not atherosclerotic, are the large and medium-sized arteries, veins, and nerves in the legs and feet. The etiology is unknown, but it includes hereditary susceptibility, tobacco exposure, and immune and coagulation responses. Several things set Buerger's disease apart from atherosclerosis are the pathology's location (affecting both the upper and lower limbs), the presence of superficial venous thrombosis, the lack of atherosclerotic risk factors, and the healthy proximal large arteries (Cacione et al., 2020). Typical symptoms of TAO in younger individuals include ischemic ulcers, rest discomfort, claudication, numbness or tingling in the extremities, migrating thrombophlebitis, and Raynaud's phenomenon. Individuals with a history of limb infection at diagnosis may benefit from a more active and cautious therapeutic

approach, as this condition has an independent link to vascular events and amputation. Quitting smoking significantly reduces vascular events and amputation rates (Le Joncour et al., 2018).

Researchers have discovered that oxidative stress, macrophages, lymphocytes, inflammation, and apoptosis can contribute to the occurrence and development of TAO using immune biochemical techniques (Song et al., 2018). A ligand binds to ICAM-1 expresses on the vascular endothelium, promoting the binding of monocytes to endothelial cells. It is also known that ICAM-1 is highly expressed in TAO, which is closely related to TAO-induced increased expression of inflammatory factors (Song et al., 2018).

Furthermore, VCAM-1 is expressed in vascular endothelial cells. It is involved in many important pathophysiological processes, including adhesion between lymphocytes, monocytes, and endothelial cells, and it may be an important indicator of vascular disease progression or dysfunction. ICAM-1 and VCAM-1 have been reported to be closely related to the incidence of TAO (Song et al., 2018). The combination of genetic predisposition and unfavorable environmental factors, especially nicotine, could result in inflammation that causes endothelial dysfunction. It is observed in histological preparations that inflammation and thrombus are present. It is possible that endothelin-1 affects these processes. Despite its wide spectrum of biological actions, it can be a powerful vasaconstrictor and can often have the opposite effect of prostacycline analogs. According to Czarnacki et al, subjects with toe necrosis had a greater concentration of endothelin-1 compared to controls without these changes (Czarnacki et al., 2004).

Even more than 100 years after TAO was first described, little is known about its pathogenesis. Genetic polymorphisms, tobacco exposure, and immune-mediated responses seem to interact because of hereditary susceptibility. A spectrum of antibodies associated with the disease may be a result of a variable immune response to tobacco, which may lead to a pathway-specific treatment. A further translational study of immuno adsorption, a therapy that allows the elution and in vitro testing of the adsorbed material, may follow the encouraging response of the initial study (Ketha & Cooper, 2013).

Conclusion

Buerger's disease has an unknown etiology. As a matter of fact, it is beyond doubt that tobacco use is closely related to disease activity (Akar et al., 2016). There are several potential etiologic factors, including genetic predisposition, immune-mediated mechanisms, hypercoagulable states, and an oral infection-inflammatory pathway. It remains controversial whether thrombotic risk factors, including factor V Leiden, prothrombin 20210G/A mutations, hyperhomocysteinemia, and platelet aggregation responses, play a role in TAO patients (Akar et al., 2016).

There is still much to learn about the disease's immunological basis, which is an important part that has yet to be fully explored. Several studies have demonstrated that T cell infiltration and activity are important factors in the pathogenesis of the disease. Based on the T 17 cells, the immune system can maintain a balance against autoimmune diseases. There is a greater infiltration of CD 3 positive T cells in the arterial wall than of B cells (Tarazjani et al., 2021). A few factors are also implicated in the disease, including TNF-α, IL-1β IL-4 IL-17 and IL-23. It appears that antiphospholipid antibodies, anti-CL (anti-cardiolipin), anti-TLRVYK (anti-hexapeptide), anti-TLRIYT (Porphyromonas gingivalis), anti-TLALYK (anti-Treponema denticola) are the likely causes of the disease. The role of anti-neutrophil cytoplasmic antibodies in the disease is also controversial (Tarazjani et al., 2021).

Detection of genetic mechanisms for the determination of molecular functions such as heparin binding, chemoattractant activity, growth factor activity associated with TAO disease and revealing their relationship with genes will enable to elucidate the molecular pathogenesis of the disease. In addition, by elucidating the immunopathogenesis of TAO, factors contributing to altered immune function and vascular tissue inflammation will be identified. The results of this investigation could serve as a basis

for additional experimental studies to confirm the identified genes and pathways and their function in the onset and development of TAO. In this regard, it can support the bioinformatics analysis data we obtain by identifying genes and pathways associated with TAO using techniques such as NGS (Next Generation Sequencing) and transcriptome analysis.

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Chapter 8

Diabetes Diagnosis with Reinforcement Learning

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Abstract

The aim of this study is to evaluate the applicability and performance of the Linear Upper Confidence Bound (LinUCB) algorithm in the diagnosis of diabetes. The research examines the performance of the LinUCB algorithm, one of the reinforcement learning algorithms, in classification problems and how it can contribute to the early diagnosis of diabetes using the Pima Indians Diabetes Dataset. The LinUCB algorithm was modeled to be suitable for classification tasks and tested with three different dataset variations: Original, Undersampling, and Smote. The performance of the model was evaluated using the cross-validation method and metrics such as accuracy, sensitivity, precision, F1-score, and AUC. It was found that the LinUCB model can also be used in classification tasks and can achieve higher metric results, especially when used with the balanced dataset variation using the Smote technique. The performance results of the model were evaluated with various metrics, indicating that it is at a developable level, even if not sufficient for classification tasks like diabetes diagnosis. This study demonstrated the potential use of the LinUCB algorithm as a tool in diabetes diagnosis. Future research is recommended to use different data preprocessing techniques and perform hyperparameter tuning to improve the performance of the model, which was found insufficient in this study for diabetes diagnosis.

Keywords Classification · reinforcement learning algorithms · linucb algorithm · diabetes diagnosis · pima indians diabetes dataset

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Introduction

Diabetes is a disease that is widespread worldwide and rapidly becoming more prevalent (Sapra & Bhandari, 2024). From 108 million cases in 1980, the number of diabetic patients increased to 422 million by 2014, and it is known that this number is rising rapidly, especially in low and middle income countries (World Health Organization, 2023). Diabetes, which has two main types, Type 1 and Type 2, is a metabolic disease characterized by inadequate blood glucose control. In addition to traditional treatment methods, technological solutions have been implemented to manage diabetes, and in recent years, machine learning algorithms have also been utilized (Fregoso-Aparicio et al., 2021).

Machine learning is based on algorithms extracting patterns and relationships from datasets to perform a specific task. Essentially, machine learning methods are divided into three categories: "Supervised Learning", "Unsupervised Learning", and "Reinforcement Learning" (RL). They are used in various fields based on their structures and functions.

The RL method is based on a trial and error process, and its algorithms learn in this way. Due to the presence of exploration and exploitation, there is a balance between these depending on certain variables. Exploitation is the prominent action as a result of what has been learned, while exploration involves other actions. In RL, there is no teacher as in supervised learning, but there is a reward / punishment mechanism based on the outcomes of actions taken. The agent in the algorithm chooses and implements actions based on the situation each time, receives rewards / punishments, and improves itself based on the rewards / punishments received. Thus, aiming to achieve the highest reward / the lowest punishment, it learns what to do or not do in each situation. RL is typically used in fields such as industrial robots, unmanned aerial vehicles, determining advertising or marketing strategies, game theory and strategies, stock and foreign exchange trading strategies, medical treatment planning, and drug dosage adjustments (Alpaydın, 2018; Gürsakal, 2018; Lonza, 2019; Ravichandiran, 2020; Sutton & Barto, 2018; Zhang et al., 2023). In the study conducted by Coronato, Naeem, De Pietro, and Paragliola (2020), the applications of RL in the healthcare sector were examined. The research indicates that RL is well-suited to the current goals of clinical research, which aim to personalize treatments and discover new therapeutic methods. Due to its potential to support the development of personalized treatments, it has garnered interest from the medical community and may play a significant role in healthcare.

Problems addressed with RL methods and the algorithms developed for solving these problems are categorized into subgroups in terms of logic and functioning (Sutton & Barto, 2018). "Multi-armed bandit" (MAB) problems, a subgroup of RL problems, can be thought of as simulating slot machines. In these problems, the actor, who has no information about the reward probabilities, repeatedly tries to select the arm that will provide the highest reward (Lonza, 2019). The "Contextual multi-armed bandit" (CMAB) problem, a variation of the MAB problem, involves an actor who has various contextual information about the arms and uses this information in the decision-making process (Ravichandiran, 2020). Therefore, just as a medical doctor uses diverse information to diagnose diseases, algorithms developed for CMAB problems can also be employed in disease diagnosis.

The Linear Upper Confidence Bound (LinUCB) algorithm is developed for CMAB problems. The LinUCB algorithm constructs a linear model for each arm. This model uses the arm's feature vector to predict the potential reward and also calculates an "Upper Confidence Bound" (UCB) for each arm. During the UCB calculation process, a balance is established between exploration and exploitation. This balance ensures that the less frequently selected arms still have a chance of being chosen, considering the possibility that the obtained reward may be greater than the predicted reward. This UCB expresses the uncertainty of the predicted reward (Chu et al., 2011; Lattimore & Szepesvári, 2020; Li et al., 2010; Mussi et al., 2023). At each step, the LinUCB algorithm considers the potential reward and the UCB to

select the best arm. The LinUCB algorithm is used in a repeated process with each incoming data to learn the most appropriate actions to best achieve a specific goal for the user. Therefore, it is widely used in areas such as online advertising, recommendation systems, and medical treatment planning (Berrevoets et al., 2022; Den Hengst et al., 2020; Gutowski et al., 2018; Lu et al., 2021; Tejedor et al., 2020; Tewari & Murphy, 2017; Wei et al., 2021).

When the research on disease diagnosis using machine learning methods and algorithms in the literature is examined, supervised learning methods and algorithms are predominantly observed (Agushaka & Ezugwu, 2020; Chang et al., 2023; Choubey & Paul, 2016; Doğru et al., 2023; Kamble et al., 2016; Korkmaz & Kaplan, 2023; Palanivinayagam & Damaševičius, 2023; Powar et al., 2023; Sehly & Mezher, 2020). Therefore, the use of RL methods and algorithms, especially algorithms developed for CMAB problems, in disease diagnosis can provide different perspectives for future research and has the potential to contribute to the literature in this field.

This study aims to determine the applicability of the LinUCB algorithm, which is widely used in various fields, for the diagnosis of diabetes.

Materials and Methods

Dataset

In this study, the "Pima Indians Diabetes" (Pima) dataset, which contains the results of a study conducted on Pima Indian women living in Arizona, USA, available on the Kaggle platform, was used. This dataset is frequently used in diabetes research and provides critical information related to the early diagnosis of diabetes. The dataset comprises data from a total of 768 participants, 500 of whom are non-diabetic and 268 of whom are diabetic. It includes 8 features and one target feature for each individual. The dataset contains features such as "Pregnancies", "Glucose", "Blood Pressure", "Skin Thickness", "Insulin", "BMI", "Diabetes Pedigree Function", and "Age", and a target feature called "Outcome" indicating whether the individuals are diabetic, with 1 class being diabetes positive and 0 class being diabetes negative (UCI Machine Learning & Kaggle Team, 2012). It is known that features such as "Glucose", "Blood Pressure", "BMI", and "Insulin", which are also included in the Pima dataset, play an important role in diabetes diagnosis. Table 1 provides basic statistical information related to this dataset.

Table 1

Pima Dataset Overview and Statistical Summary

Features	Data Type	Mean	SS	Min	Median	Max
Pregnancies	Numerical	3.85	3.37	0.00	3.00	17.00
Glucose	Numerical	120.89	31.97	0.00	117.00	199.00
BloodPressure	Numerical	69.11	19.36	0.00	72.00	122.00
SkinThickness	Numerical	20.54	15.95	0.00	23.00	99.00
Insulin	Numerical	79.80	115.24	0.00	30.50	846.00
BMI	Numerical	31.99	7.88	0.00	32.00	67.10
DiabetesPedigreeFunction	Numerical	0.47	0.33	0.08	0.37	2.42
Age	Numerical	33.24	11.76	21.00	29.00	81.00
Outcome	Categorical (0 and 1)	-	-	-	-	-

SS: standart deviation

Data Preprocessing

First, the Pima dataset was checked for any missing values, and none were found. Then, because the zero values in the "Glucose", "BloodPressure", "SkinThickness", "Insulin", and "BMI" features are not realistic, these values were considered missing and were imputed using the "KNNimpute" method (Troyanskaya et al., 2001) with k=5, replacing them with the averages of other data points with similar features. Next, descriptive statistics were examined to determine the central tendency and distribution of the features in the dataset. Finally, since the dataset contains a small number of data points, rows with outliers were not deleted. Instead, to reduce the scale differences between features and the effects of outliers, scaling was performed using the "RobustScaler" method (Scikit Learn, 2024).

Dataset Variations

Due to the structure of the LinUCB algorithm and the classes of the target feature (0 and 1), the model uses two separate arms and linear models (Chu et al., 2011; Li et al., 2010). It is believed that the algorithm can achieve more accurate results when evaluating its options if these separate linear models for each arm receive a similar number of training updates or corrections. Considering this and the imbalance in the target feature of the dataset, with 500 samples in class 0 (approximately 65%) and 268 samples in class 1 (approximately 35%), three different dataset variations were used in the study to determine the impact of the imbalance: the original "Original" dataset variation, the "Under-sampling" dataset variation balanced by applying the "Under Sampling" method (He & Ma, 2013), which removes random samples from the majority class to increase the proportion of the minority class, and the "Smote" dataset variation balanced by applying the "Smote" method (Chawla et al., 2002), which synthetically increases the samples of the minority class to achieve class balance.

LinUCB Algorithm

LinUCB is a RL algorithm developed for CMAB problems (Lattimore & Szepesvári, 2020). It has the ability to select optimal actions based on user or context features. LinUCB effectively balances exploiting the best-known action and exploring less-known actions. This allows the model to evaluate actions with expected high rewards while also considering other actions, thereby expanding its knowledge base (Chu et al., 2011; Li et al., 2010).

LinUCB predicts the expected rewards of actions using the linear relationship between feature vectors and action parameters. At each step, the action with the highest score, calculated using the following formula where the feature vectors ($x_{t,a}$), action parameters ($\hat{\theta}_t$), and exploration-exploitation balancing parameter (Alpha (α)) play significant roles, is selected ($p_{t,a}$) and that action is executed.

$$p_{(\mathrm{t,a})} = \hat{\theta}_{\mathbf{t}}^{\mathbf{T}} x_{(\mathrm{t,a})} + \alpha \sqrt{x_{(\mathrm{t,a})}^{\mathbf{T}} \mathrm{A}_{\mathbf{a}}^{-1} x_{(\mathrm{t,a})}}$$

LinUCB updates the information matrix (A) and the target vector (b) with the following formulas to improve its future predictions by analyzing the rewards/punishments obtained from the actions taken at each step.

$$\mathrm{A}_{\mathbf{a_t}} = \mathrm{A}_{\mathbf{a_t}} + x_{(\mathbf{t,a})_\mathbf{t}} x_{(\mathbf{t,a})_\mathbf{t}}^{\mathbf{T}} \quad b_{\mathbf{a_t}} = b_{\mathbf{a_t}} + r_t x_{(\mathbf{t,a})_\mathbf{t}}$$

LinUCB Model Details

While developing the LinUCB algorithm model, the Sherman-Morrison formula was used to enhance performance in computational intensity (Ciucanu et al., 2022; Kveton et al., 2019; Vernade et al., 2020). The reward variable was set to +1 for correct predictions and –1 for incorrect predictions. The alpha (α)

parameter, which balances exploration and exploitation, was fixed at a value of 1.25 for both arms. In arm selections, the action with the highest value was chosen, and in the case of equal values, the action was selected randomly. Additionally, during the testing phase, the exploration element was removed and no updates were performed to measure the model's training level and performance.

Model Implementation

In the LinUCB algorithm, the decision on which arm to select is based on the highest $p_{t,a}$ value. As can be understood from the calculation formula, the context of the first data in the training phase and the same values of other variables except the alpha (α) value (Chu et al., 2011; Lattimore & Szepesvári, 2020; Li et al., 2010) and the use of the same alpha (α) values in the arms in the model developed for this research lead to an equal starting condition for the training, meaning the model begins training by selecting a random arm initially. This randomness in both the initial data and every equality situation prevents performance evaluation metrics from obtaining stable results. Therefore, all dataset variations were run 1000 times.

Model Performance Evaluation Method and Metrics

The model's performance measurements were conducted using the “Stratified Cross Validation” method with k=5 to maximize data utilization and reduce variance (Hosmer & Lemeshow, 2000). Additionally, a “Confusion Matrix”, which presents the correct and incorrect predictions in classification problems in detail, was used (Powers, 2020). The model's performance was evaluated using “Accuracy”, “Sensitivity”, “Precision”, “F1-score”, and “AUC” metrics. The AUC (Area under the ROC Curve) measures the area under the ROC (Receiver Operating Characteristic) curve, which shows the model's performance at all possible threshold values, with the “True Positive Rate” (TPR) on the vertical axis and the “False Positive Rate” (FPR) on the horizontal axis. It is an important metric for evaluating the model's discriminative ability. Although the ideal AUC value may vary depending on the application area, some sources in the literature indicate that values of 0.7 and above represent acceptable discriminative ability, and values of 0.9 and above indicate outstanding discriminative ability (Bobbitt, 2021; Fawcett, 2006; Hosmer & Lemeshow, 2000; Mamun et al., 2022; Mandrekar, 2010).

Results

To provide a broad overview of how the model performs on different datasets and to help us understand the model's generalization ability, average performance values were used when evaluating the overall success of the model. The average values of the obtained performance evaluation metrics are presented in Table 2.

Table 2

Comparison of Average Performance Evaluation Metrics

Dataset Variation	Accuracy	Sensitivity	Precision	F1-score	AUC
Original	0.70	0.84	0.55	0.66	0.73
Undersampling	0.74	0.86	0.69	0.76	0.74
Smote	0.75	0.90	0.69	0.78	0.75

SS: standart deviation

According to Table 2, it is observed that the model performs differently on the original and balanced datasets. When used with the original dataset variation, the model yielded lower performance evaluation metric results, whereas much higher results were obtained when used with the balanced dataset

variations (Undersampling and Smote dataset variations). Among the balanced dataset variations, the model showed significant increases in sensitivity and F1-score metrics when the Smote dataset variation was used. This indicates that the Smote technique is more effective than the Undersampling technique in accurately identifying diabetic patients. However, it was also observed that the precision metric was not sufficiently effective, indicating that the model needs further improvement in reducing false positive predictions. Although the model's AUC metric results are at acceptable levels, there is still a need for further development for health research.

Discussion

The imbalance in the target feature of the Pima dataset has significantly affected the overall success of the model. Additionally, when comparing the applications made with balanced dataset variations among themselves, we observe the impact of the number of data points. When examining the classification studies conducted with the Pima dataset in the literature, it is seen that classical classification and deep learning algorithms are mostly used, and the results obtained are generally higher than those of this study.

Doğru, Buyrukoğlu and Arı (2023), proposed a hybrid system for early diabetes diagnosis using different datasets in addition to the Pima dataset. They created this hybrid system using four base learners: Logistic Regression, Decision Tree, Random Forest, and Gradient Boosting, along with a meta-learner (Support Vector Machines). They found an accuracy result of 92% using the Pima Dataset.

Palanivinayagam and Damaševičius (2023), conducted research using the Pima dataset on how to fill in missing data and subsequently diagnose diabetes using classification algorithms. They used Naive Bayes classifier, Support Vector Machines, k-Nearest Neighbors, Random Forest, and Linear Regression algorithms and reported that the highest accuracy rate of 94.89% was achieved by Support Vector Machines.

Korkmaz and Kaplan (2023), conducted a study on diabetes diagnosis using the Pima dataset, achieving accuracy metric results with Logistic Regression (84.58%), k-Nearest Neighbors (84.59%), Classification and Regression Trees (85.02%), Random Forest (88.29%), Support Vector Machines (84.73%), Extreme Gradient Boosting (89.29%), and Light Gradient Boosting (88.72%) algorithms. After hyperparameter tuning, they reported achieving accuracy metric results of 89.30%, 90.01%, and 90.01% with Random Forest, Extreme Gradient Boosting, and Light Gradient Boosting algorithms, respectively.

There are numerous studies conducted using the Pima dataset for classification. In these studies, very different accuracy metric results have been achieved. Upon examining the studies, it was observed that the differences in accuracy rates stem from different data preprocessing steps, different hyperparameter settings, and the use of different algorithms (Agushaka & Ezugwu, 2020; Chang et al., 2023; Choubey & Paul, 2016; Kamble et al., 2016; Powar et al., 2023; Sehly & Mezher, 2020). Most of the algorithms used are classification algorithms, and there are few studies that use RL algorithms for classification. In the health field, it is generally observed that the use of RL algorithms focuses on personalized treatment, and no study using RL algorithms for diagnosing diabetes with the Pima dataset has been found.

Conclusion

This study revealed that the model developed for diagnosing diabetes did not demonstrate sufficient performance. It is thought that factors such as the fixed alpha variable and the small number of data points negatively affected the model's performance. Future research is recommended to evaluate

the impact on model performance by applying different data preprocessing techniques and hyperparameter tuning.

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Chapter 9

Evolution of Digital Assets: The Role of Blockchain Technology in Non-Financial Sectors

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Abstract

Blockchain is a decentralized technology that enables the transfer of valuable assets in a virtual environment and the secure storage of data. It enables information to be provided without the need for any certification institution and documents can be securely transferred in a virtual environment. This pioneering technology has proven itself in the field of finance and is causing structural transformations in various other sectors. Although blockchain technology has some inherent limitations as a new paradigm, its continued development will bring significant changes. Those who can keep up with this transformation will play an important role in its evolution. It is possible to evaluate this study in two parts. The first part examines the operating mechanisms and evolution of cryptocurrencies, which are the first area of use of blockchain, and analyzes its various applications. In the second part, a systematic review was made on the use of blockchain technology in different sectors. In particular, the innovations that the smart contract mechanism will offer as an alternative to traditional data storage tools in basic social areas such as real estate, health, education and law were mentioned. The compatibility of legal regulations and developed algorithmic bases with smart contracts is of critical importance for the permanence of the technology. The main point that is aimed to be emphasized as a result of the study is that the innovations that blockchain technology can provide in non-financial fields such as transaction cost, transaction speed and security can realize institutional transformations.

Keywords Blockchain · crypto currency · decentralized finance

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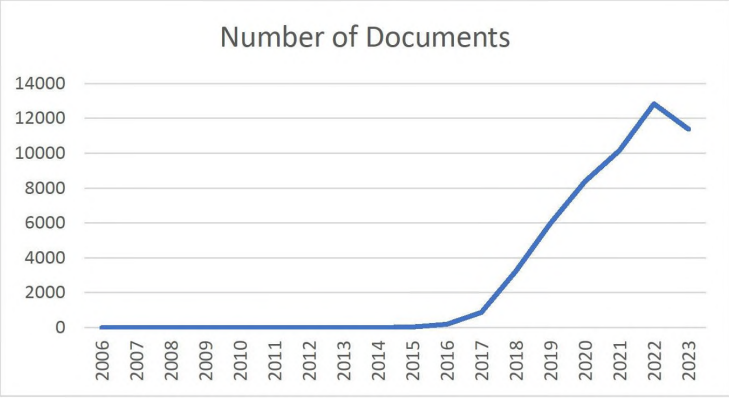
Introduction

Today, digitalization and technological advances create serious changes in many sectors. Blockchain technology is radically changing traditional structures by offering a wide range of applications, from financial systems to healthcare, from supply chains to voting processes. In this part of the book, the current usage areas and future place of this innovative technology are discussed by examining the field distribution in the literature. Starting from the history of blockchain, understanding its basic concepts, usage areas and sectoral distribution is important to fully grasp the potential of this technology. A search was made by typing “blockchain” in the Scopus database, and the trend analysis by year is given in Figure 1.

Figure 1

Number of Publications by Years



Satoshi Nakamoto's 9-page article in the immediate aftermath of the 2008 Global Financial Crisis brought about a new technological era through blockchain (Nakamoto, 2008). Although Nakamoto achieved a major milestone in 2008, it was observed that blockchain took a significant place in the literature in 2015 and later. This date coincides with the time when cryptocurrencies began to be widely used. The main driver of blockchain technology's popularity is Bitcoin, consisting of information blocks linked together through a cryptographic encryption known as Bitcoin. Cryptocurrencies have now become widely used worldwide.

The purpose of this study is to elucidate the operational mechanism of blockchain technology, as well as its current utilization and products in the finance and other sectors. It is important to analyze the technology's usage in the realm of cryptocurrencies, hence the decision to begin with the examples of Bitcoin and Ethereum, which are the pioneering areas of blockchain technology and have seen significant transaction volumes. Alpha instruments differ from Ethereum in their quantity and number of players. Meanwhile, the introduction of the "smart contract" concept through the Ethereum product has broadened the potential applications of blockchain technology, representing a significant advancement. For a more precise analysis of this study, a methodological approach to blockchain is necessary. Technology and its unique features, benefits, critiques, and potential applications are compared and analyzed in this discussion.

Blokchain Technology

Due to the unique structure of blockchain technology, users have the ability to transfer their assets in a digital and decentralized environment according to specific rules. In the blockchain system, all

values or data are unalterable and are securely encrypted (Peng et al., 2024). All assets transferred between the parties are stored in a digital ledger that is transparently accessible to each user (Crosby et al., 2016).

In traditional finance systems, all financial transactions are recorded in a central ledger. However, blockchain technology is decentralized and operates differently.

Information records are useful not only for financial assets but also for storing any data. All users who participate in processing the data flow in question can provide additional contributions. This is because all users have clear access to this information. Data flow within the blockchain operates in this manner. Therefore, after being recorded once, operations cannot be altered (Woodside et al., 2017). The accumulation of blocks within the chain is the result of each user approving their respective transactions. For instance, the sender sends a cryptographic structure to the receiver who then approves it, leading to the recording of the relevant transaction onto the blocks. This way, digital activity on the system is secured. Signatures are verified, and similar transactions can be continued over blocks (Usta & Doğantekin, 2017). As a result of this situation, asset transfer and data recording can be carried out between the parties without the need for any intermediary institution or person.

Blockchain technology was initially developed for the creation and circulation of cryptocurrencies in the financial system. Although it has been utilized, blockchain has managed to attract the interest of non-financial industries in a short amount of time. The unique properties of blockchain offer an alternative to traditional structures. The main advantages of this new technology are listed below. The main benefits of this new technology can be listed as follows.

- Each user has a unique and systematic algorithm-generated personal user identity. Each transaction recorded on blocks is encrypted and stored separately. Only users included in the same chain can access these transaction records. As the number of transactions increase users can add information blocks. However, changing the structure of records is theoretically possible but quite difficult. Every new participant joining the blockchain contributes to the formation of the next blocks that follow the chain with their new transactions. It is crucial for the safety of the chain that each additional participant represents a new security element that needs to be broken. Therefore, an increase in the number of participants in the chain is a quantitative factor that enhances encryption security.
- Since the data records or asset transfers that take place can be seen by other users in the chain, the transparency of the system can be mentioned. Transactions are recorded in sequential order in blocks as a result of numerous users granting approval for transaction requests.
- One of the most fundamental principles underlying blockchain technology is its lack of a centralized structure. Instead, it facilitates ease of transaction between sender and receiver independent of intermediaries. Transactions are authorized by mutual agreement between both parties, allowing for reduced transaction costs and increased transaction speed. However, this feature also removes the possibility of correcting erroneous transactions (Utkina, 2023).
- The increased adoption of smart contracts results in reduced transaction costs and faster transaction speeds, offering another unique advantage to the system. Smart contracts are agreements with self-executing functions, in which user representation occurs through coded programming (Wang et al., 2019). The development of smart contracts has been led by blockchain technologies such as Ethereum and Hyperledger. The introduction of Ethereum in 2015 demonstrated the potential for blockchain beyond cryptocurrency transfers through the use of smart contracts, expanding the scope of blockchain application (Sehra et al., 2018).

Despite the numerous innovations and benefits of blockchain technology, criticisms still exist regarding its ongoing uncertainties and issues due to it being a relatively new technology. Common criticisms directed towards the system can be summarized as follows (Güven & Şahinöz, 2018).

- The current capacity for global trade volume and daily transaction intensity raises questions about adequacy. For instance, there are significant differences between the monetary size and transaction volume occurring in one second within the world banking system and the transaction capacity of cryptocurrencies.
- Due to the lack of widely accepted approval by central banks and governments, there are legal infrastructure deficiencies that pose a problem. There is a need for consensus between organizations and governments to establish standard rules and monitoring mechanisms.
- Due to the lack of widely accepted approval by central banks and governments, there are legal infrastructure deficiencies that pose a problem.
- The energy consumption from data mining and cryptocurrency production seriously contributes to energy waste. The already limited supply of cryptocurrencies will face additional pressure on their value due to such high production costs, while also bringing ecological concern.

Bitcoin

Bitcoin is a cryptocurrency that features the first implementation of blockchain technology, as described in Nakamoto's (2008) article. Compared to thousands of other cryptocurrencies, Bitcoin is more popular and has a higher transaction volume due to being associated with the new technology as its first application example. Despite being a digital currency with limited supply, Bitcoin is not printed by any central bank.

Bitcoin possesses the fundamental tenets of a decentralized structure based on blockchain technology, including independence from governments and central banks and a distributed ledger system. The price of Bitcoin is determined by the direct willingness of users to pay, in accordance with the current market context. Therefore, the market value of Bitcoin is proportional to its brand strength and reputation compared to all other cryptocurrency or physical assets.

Ethereum

Ethereum, a cryptocurrency that utilizes blockchain technology similar to Bitcoin, was introduced to the market in 2015. The creator of Ethereum is a Russian-Canadian computer programmer named Vitalik Buterin, born in 1994. Ethereum, a cryptocurrency that utilizes blockchain technology similar to Bitcoin, was introduced to the market in 2015. Since then, it has become the most traded digital currency in the cryptocurrency market, following Bitcoin. Buterin made a name for himself in the blockchain community by launching "Bitcoin Magazine" in 2011 with a focus on cryptocurrency. In the following two years, he began to advocate for coding within the Bitcoin system, causing a rift with orthodox Bitcoin supporters. Thereupon, he developed the concept of "Smart Contract", the foundations of which were laid before him, with his individual efforts and created a new cryptocurrency and named it "Ethereum".

While sharing many similarities in terms of usage with Bitcoin, Ethereum differs significantly in technical aspects and applications. Unlike Bitcoin, Ethereum mining is done using GPU instead of CPU. In other words, a graphics card is used instead of a motherboard for Bitcoin mining. Due to its high technology and cost requirements, it is not commonly preferred by users who have technological capabilities for household use. One of the main criticisms of Bitcoin is its high energy consumption. Due to these features, Bitcoin's supply is believed to be dominated by a few large data miners. Ethereum, designed to address criticisms, exhibits an anti-monopoly structure by enabling many small users to

engage in mining. On the other hand, Ethereum's biggest contribution to blockchain technology is that it contributes to the development of smart contracts, making it possible to use them in different sectors. When discussing the use of smart contracts in many areas, it is important to remember Ethereum's popularity in the world as well as its contributions to software.

Evaluation of Cryptocurrencies According to Traditional Monetary Theory

Financial assets created by blockchain technology are described as crypto or digital money. However, they do not always fulfill the definition and functions of classical monetary theory. Due to these distinctions with the traditional concept of money, Bitcoin and other cryptocurrencies that today's monetary system could be completely replaced in the near future are the main obstacles.

When analyzed through the basic functions of money; Bitcoin serves as a medium of exchange undertakes. The fact that it is not a physical asset eliminates statute of limitations risks such as wear and tear. Strengthens its store-of-value characteristic by removing the risk of price volatility. However, the extreme volatility of its price creates insecurity in terms of custody. Also, short-term and large changes in the price fluctuations in scale make it difficult for cryptocurrencies to function as a unit of measurement.

When considering the characteristics of currency, it becomes evident that Bitcoin shares many similarities with modern-day currency. As Bitcoin's popularity increases, its acceptance and monetary validity also increase. However, the value of Bitcoin exhibits high levels of variability in a short period. The stability of its monetary value contradicts with Bitcoin's main purpose of serving as an alternative to modern-day currency, which is one of the biggest criticisms directed towards it. However, in terms of portability, Bitcoin's structure allows it to have an advantage over traditional currency. The relative low cost and flexibility to transfer at any time make Bitcoin much more practical than the transactional mobility provided by today's banking system. Finally, the ability to divide Bitcoin into one millionth subunits is consistent with the divisibility characteristic of currency. Thus, it can be said that it is highly suitable for commerce and shopping (Güven & Şahinöz, 2018).

Use of Blockchain Technology in Finance and Non-Finance Service Sectors Areas

Blockchain technology, while first and primarily associated with cryptocurrencies, has been increasingly implemented in various industries over time. Its decentralized structure, trustworthy, transparent, and traceable nature are some of the main reasons it has garnered attention across different sectors (Bhaskar et al., 2020). The use of blockchain technology in the healthcare sector allows individuals to safeguard their health data and share it securely, facilitating effective data utilization. While academic models have been proposed in literature, commercial companies also offer such services. Zhang et al. (2022) proposed an e-health system based on blockchain technology to ensure the security and privacy of patients' electronic health records. MeDShare allows for the monitoring of entities accessing data for malicious purposes and provides a data storage system. MedShare is a system that utilizes smart contracts and an access control mechanism to revoke access to organizations violating permissions. Through the use of MedShare, cloud service providers obtain data control with low risk concerning data privacy when sharing medical data between research and clinics (Xia et al., 2017). Consequently, the use of a single blockchain model is not yet possible in every subunit of the healthcare sector. The commercial venture Pokitdok provides a blockchain platform that simplifies asset transfer between potential intermediaries and supports all types of transactions and transfers among various devices, patients,

and other relevant stakeholders (Miller, 2017). In the study where IoT and blockchain technology are used together to manage the healthcare supply chain and protect medical records, the blockchain network Hyperledger Fabric, which allows only authorized and registered users to access the ledger and transactions, was used. In the performance evaluation conducted within the scope of the study, it was found that the proposed solution would be suitable for large-scale environments (Rizzardi et al., 2024). The resolution of current issues could be achieved through the development of various blockchain models (Aydar & Çetin, 2020).

In the real estate sector, the use of blockchain technology allows stakeholders to simultaneously access property records during land and title ownership transactions. This eliminates potential property disputes. However, when buying or selling property, there are still other considerations to take into account. Information asymmetry creates many risks since it is difficult to achieve symmetry in acquiring and obtaining information. This creates a barrier to fair pricing behavior, as information asymmetry means that sellers have an information advantage over buyers. Before a sales transaction, information asymmetry poses a serious problem. After the sale, another negative result is the problem of adverse selection. Due to the unfair valuation of asset prices, individuals seeking to use real estate loans will agree to high-interest and risky loans to cover prices well beyond the fair value. This condition leads to the formation of bubbles in the real estate market and increases the rate of non-performing loans in the banking sector, posing a significant threat to the financial system. Asymmetry of information and adverse selection exacerbate this issue. The most crucial factor in mitigating election issues is ensuring that both buyers and sellers have transparent access to information regarding the products and prices involved in the process. This prevents the formation of asset price bubbles and minimizes inefficiencies in resource allocation, such as with credit distribution. In addition, the complexity, time-consuming nature, and high brokerage fees associated with real estate transactions present a separate issue. To address these problems, Tan and Nguyen (2022) have proposed a model. The developed Real Estate Transaction Monitoring Model enables the monitoring of all real estate transactions to occur smoothly. Stakeholders can manage and track the entire process of real estate transactions, as well as review the entire purchase or rental history of a property. This model enhances transparency and mutual trust in real estate transactions, eliminates intermediaries, and reduces transaction costs.

The use of real estate investment trusts (REITs), which express joint ownership of physical assets in the real estate industry except for direct buying and selling, is becoming widespread and playing an essential role in the development of the capital markets. In simple terms, REITs address the increasing housing demand and the construction of new developments. This system provides an opportunity for low-income communities who lack the ability to purchase homes to invest in real estate projects and obtain alternative funding for such projects. The system is based on public offerings through capital markets. Individuals with insufficient savings for home purchases can become shareholders in real estate projects in proportion to their capital contributions. The owners of residential properties or projects can profit in proportion to their ownership share from the increase in the value of the properties. Moreover, the undertaking of real estate projects may contribute to the growth of the sector by creating alternative and interest-free sources of funding for companies, apart from bank loans. In addition, it is expected that these projects will promote the development of the industry. Real estate assets that have a static nature are included in the financial system through securitization with certificates (Aypek, 2012). Smart contracts, an innovation introduced by blockchain technology, are a result of the structure of real estate transactions. The goal is to ensure transaction security and ease of use while eliminating the costs of intermediaries and the need to store large numbers of documents. To achieve this, it is necessary for each blockchain structure or smart contract involved in the process to conform to commonly accepted legal regulations recognized by authorities. Therefore, separate regulations and legislation should be prepared according to the nature of transactions to be carried out in the industry.

In this context, it is anticipated that the blockchain technology will enrich the production and financial aspects of the real estate sector with the widespread use of smart contracts.

Blockchain applications are also found in the education sector. One such application is the instant inputting of students' course credits from different educational institutions into the system, which can be viewed by all institutions. Blockchain is also used to track and process scholarships and payments, as well as to store education identity information such as diplomas and certificates on a digital platform (Fleener, 2022); (Turkanović et al., 2018). Student-centered blockchain-based solutions are preferred due to their ability to expedite and simplify the administrative procedures required for verification processes. Educational institutions can greatly benefit from such solutions. This allows for certificates, diplomas and other necessary documents that require validation from intermediary institutions to be validated without the need for such institutions, thereby streamlining bureaucratic processes for individuals and organizations seeking to verify these documents (Grech & Dos Santos, 2017). From an objective standpoint, processing tuition fees, accreditation procedures, automatic transfer of ECTS credits, and grant funding utilizing blockchain-based technologies provides administrative and operational convenience to the units that will execute these transactions. It is observed that when solved, this process provides ease in terms of management and operations for units that will carry out these operations (Kamisalic et al., 2019). This system benefits both students and institutions. EduCTX is a blockchain-based platform that provides a reliable and decentralized system for transferring education credits and grades for higher education institutions that can be accessed by all stakeholders globally (Turkanović et al., 2018). While blockchain technology has the potential to accelerate processes and provide increased ease in education, its limitations have been examined in various dimensions within literature. Nevertheless, educational institutions collect vast amounts of data from their students, thus requiring peer-to-peer validation for every transaction. The lack of shared standards for ensuring interaction between networks and the difficulty of integrating with legacy systems present a disadvantage for interoperability (Upadhyay, 2020). This situation increases the number of blocks and transactions on the blockchain, leading to the need for more processing time (Steiu, 2020). In a study examining the challenges of using blockchain technology in the education sector, difficulties were classified as technological, organizational, and environmental. According to this classification, challenges include poor usability, lack of scalability, limited interoperability, and constraints on collaborative work. Technological issues include lack of standardization, integration complexity, security concerns, privacy, inflexibility and immutability. Organizational challenges consist of skill shortages, financial barriers, and lack of management support. Legal issues, compliance gaps, market and ecosystem readiness, and sustainability concerns are all environmental difficulties (Mohammad & Vargas, 2022).

The blockchain technology offers a potential solution for ensuring transparency and accountability in the supply chain, allowing for the tracking of products from their production stages up to their end users. Its implementation accelerates the flow of goods. However, the supply chains in the food sector are highly complex due to the involvement of numerous stakeholders, which presents a challenge for ensuring transparency. This complexity holds true throughout the entire supply chain. Ensuring transparency and reliability in the food supply chain is crucial, particularly considering factors such as food safety, contamination risks, and increasing environmental and societal concerns (Shahid et al., 2020). Blockchain technology has the potential to promote food safety, thereby enhancing the entire supply chain. The process ensures accurate information flow regarding the origin of the product, transparency in transactions, traceability, and immutability throughout the chain (Salah et al., 2019).

Angelo and Orazio (2022) proposed a fully distributed model based on blockchain technology to define a supply chain management system that ensures quality, integrity, and traceability throughout the entire supply chain process. This model employs the use of smart contracts to automate supply chain management operations and provides transparency, security, and immutability to traceability

information. This model enables the addition and modification of rules during runtime, allowing for product-specific quality control mechanisms to be applied. Additionally, it provides a complete view of the various harvest, processing, and distribution stages that product series are subject to, allowing for the complete restructuring of each series' entire lifecycle.

Blockchain technology is applied using open-source solutions such as Ethereum or Hyperledger Fabric, or specialized software solutions like IBM Food Trust, Farmer Connect, Agriledger, or Grain Chain, specifically designed for food supply chains (Kraft & Kellner, 2022). However, one of its fundamental limitations is its difficult implementation in supply chain networks with low technological infrastructure. Raw materials are typically found in developing countries, while blockchain-based supply chain networks are designed for the use of developed countries. As a result, most software solutions, devices, and infrastructures do not function effectively and, therefore, the relevant technology cannot work in developing countries. Moreover, the low level of education among farmers who directly produce raw materials adds to the aforementioned issues (Kshetri, 2021).

With the advances in network technology in recent years, digital artifacts are easily accessible online. This can seriously damage the rights of data subjects and digital copyright infringement, which may affect the willingness of owners to create original works. Therefore, attention needs to be paid to the protection of digital copyrights. In a digital environment the protection of works such as music, pictures, texts is a serious problem. Every work created with blockchain technology a unique digital identity and certificate is assigned to the work on the blockchain and is available on the network is transmitted to all stakeholders simultaneously. In this way, it is possible to determine who owns the relevant work and when information about its production is public and can be proven on the blockchain network (Crosby et al., 2016). In the literature and in the applications made by start-ups, it is possible to directly create there are copyright works in the field. Various challenges hinder integration due to factors such as limited access to technology and its high cost (Kshetri, 2021). Zou et al. (2019), who took the photo and uploaded it to the internet the person loses control over the photograph, and the photographs can be edited with editing tools a new Ethereum-based system with a focus on differentiated sharing and copyright to the users. Thanks to this system, users can upload their photos without any copyright issues can share them on the internet, other users can question the authenticity of the photo, and the photos can be monitored. The Ethereum-based Ujo music company provides access to music for listeners provides a platform service for artists to receive royalties (Mattila, 2016). BMCProtector uses blockchain and smart technology to protect music copyright and rights holders' revenues is a model based on contract technology. Thanks to BMCProtector, artists are able to protect their music copyrights can easily authorize and manage it in a public ledger. Distribution of the work process without the involvement of intermediaries, rights holders receive automatic and instant royalties from the music industry can receive a larger share of their payments (Zhao & O'Mahony, 2018).

Although from a copyright point of view it is advantageous for both artists and users, keeping content on the blockchain is a storage problem with the increase in the number of users to create a new blockchain technology. The immutability of blockchain technology is one of its most important elements However, in the case of a copyrighted work, there may be a change in the ownership of the work. Therefore, since the records relating to copyright ownership may need to change, the data will not change. It is not possible to enter the blockchain with a 100% guarantee of accuracy. A new blockchain-based copyright management system can be used effectively by a large number of right holders and users and cover a sufficient number of popular copyrighted works. For this reason, one of the key challenges in implementing an effective blockchain-based copyright management system to include enough people in the system (Savelyev, 2018).

Conclusion

Blockchain technology, which emerged after the global crisis and made a name for itself with the architecture of cryptocurrencies, will lead to the structural transformation of many sectors, especially finance, in the near and distant future. The development of new financial instruments with this technology will increase investment diversity, the number of investors and the depth of markets. The smart contract mechanism, one of the innovations brought by blockchain technology, is likely to replace traditional tools in terms of data storage and security, especially in the fields of health, real estate, education, procurement and law. However, the validity of smart contracts will depend on the legislation adopted by the authorities and the usefulness of algorithmic bases designed according to the nature of the transaction to be used. On the other hand, in other goods and services sectors, the ease of intermediary-free transactions and mobility of the blockchain is expected to increase service quality while reducing transaction costs for all users. The transparency and trust offered by blockchain technology will provide reliability among users. It is thought that this technology will increase transparency and reliability in areas such as supply chain management and create a positive and significant impact. It is a fact that it will provide speed and efficiency to institutions with the transformation it will provide in processes such as verification of certificates and registration processes in the field of education. However, in order for this transformation to be fully achieved, technological infrastructures must be strengthened and the necessary standards must be established. In order for blockchain technology to be adopted and used in different areas, it must be compatible with existing systems. Otherwise, although theoretical application examples are given, it will not be possible to fully reflect it in daily life.

While many elements that act as intermediaries today, such as banks, notaries, and commercial platforms, continue to exist to the extent that they can adapt to blockchain technology, it seems highly likely that those who cannot adapt to the flow of technology or resist it will only be written in the pages of history. If it is possible to see that blockchain and its derivative technologies create a fundamental change in the structure of existing institutions and social relations, it would not be wrong to define all these developments as a digital revolution in the true sense.

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Chapter 10

Feature-Driven Campaign Success Prediction in CRM: Selective Precision

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Abstract

Businesses are proactively digitizing their operations in the current era of heightened digital transformation to maintain a competitive edge and provide groundbreaking services. As a result, the production and buildup of data have become intrinsic components of organizational operations. It is imperative to utilize this data in customer analytics applications in order to make well-informed decisions. Accurately predicting the outcomes of marketing campaigns, a critical component of successful customer relationship management (CRM), is of the utmost importance for organizations aiming to achieve long-term expansion. This paper investigates the application of predictive analytics in the domain of CRM, with a specific emphasis on the Next4biz CRM software with focus on predicting the success of campaigns. A thorough analysis of descriptive data extracted from past campaigns within the Next4biz CRM software constitutes the pilot application. To improve the precision of predictions regarding the success of a campaign, we conducted an exhaustive feature selection study. This procedure entailed the meticulous curation of pertinent attributes predicated on historical campaign data. Specifically, our findings indicate an increase in classification accuracy from 57.14% with all features to 59.14% following the feature selection process, alongside an improvement in the F1 score from 0.58 to 0.59. Not only does our research emphasize the significance of predictive analytics in contemporary CRM, but it also demonstrates the pragmatic ramifications of feature selection in enhancing forecasts of campaign success. By integrating strategic decision-making with data-driven insights, this study makes a valuable contribution to the dynamic field of customer relationship management in the digital era.

Keywords Feature selection · boruta · customer relationship management · targeted marketing

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Introduction

Within today's dynamic and highly competitive business landscape, the implementation of Customer Relationship Management (CRM) products has become an absolute necessity for organizations endeavoring to achieve and sustain a competitive advantage. CRM tools are of the greatest significance in facilitating significant connections with clients as they empower organizations to collect, structure, and evaluate extensive volumes of customer data. CRM products enable businesses to personalize their interactions and offerings in response to the ever-changing expectations of their customers, thereby increasing overall customer satisfaction. In addition to facilitating transactions, CRM platforms function as all-encompassing centers that oversee customer interactions, monitor leads, and optimize marketing strategies. By employing CRM, organizations can enhance operational efficiency and gain valuable insights into consumer behavior. This empowers them to make well-informed decisions and foster enduring, mutually advantageous relationships with their clients. As more organizations acknowledge the significance of customer-centric strategies, customer relationship management (CRM) products become indispensable instruments for navigating the intricacies of the contemporary market, guaranteeing flexibility, and cultivating long-term expansion (Rodriguez et al., 2018).

CRM products are comprised of a variety of essential services that are intended to optimize and expedite customer interactions. These platforms generally provide an extensive system for managing customer data, functioning as a centralized repository where customer information can be structured and examined. Efficient lead and contact management capabilities provide organizations with the means to cultivate connections and take advantage of favorable circumstances. Yet, campaign governance is undoubtedly one of the most crucial services contained within CRM. Campaign management tools facilitate the coordination of focused and individualized outreach endeavors for organizations, guaranteeing that marketing initiatives strike an emotional connection with distinct customer segments. This capability plays a crucial role in optimizing the effectiveness of promotional endeavors, cultivating recognition of the brand, and stimulating interaction with customers. Through the strategic development, implementation, and evaluation of marketing initiatives, organizations can not only augment their prominence but also foster enduring relationships with their target demographic. In an age characterized by the criticality of effective communication, businesses that wish to flourish in a competitive environment must possess the capability to navigate and optimize campaign strategies CRM products. This ensures that each customer interaction makes a substantial contribution to the organization's overarching objectives Ascarza et al. (2017).

Addressing a crucial and frequently neglected aspect-the exact identification of qualities in the face of rising data quantities-this paper provides a substantial contribution to the field of campaign management within CRM. Feature identification is a major difficulty in the ever-changing world of targeted marketing, where reaching the right people with the appropriate products is critical to the success of any campaign. By highlighting the significance of careful feature selection to reduce computational complexity, the paper aims to illuminate this vital component. This study intends to shed light on the complexities of data reduction in order to offer a methodical and efficient way to extract the most relevant qualities from campaign data. By doing so, it improves the effectiveness of computational operations and establishes a foundation for the creation of reliable prediction models. In essence, the paper's purpose is to provide practical insights and approaches that help optimize CRM systems and connect massive amounts of campaign data, leading to better campaign management in terms of targeting, efficiency, and success.

Following this introduction, the second section of the manuscript delves deeply into the topics of feature reduction and selection. Subsequently, in the third section, the Boruta method for feature selection is implemented. The results acquired from these methodologies are presented and analyzed

in the fourth section. Subsequently, the findings are thoughtfully discussed in the fifth section, placing them in the wider context of CRM and campaign management. The sixth and final section of the paper provides a comprehensive summary of the main findings, implications, and recommendations for further investigation concerning data reduction methods utilized in CRM campaign management.

Related Work

Effectively managing data modeling involving extensive and potentially unrelated data can be a significant obstacle, requiring a methodical and strategic approach to minimize the influence of noise. Reducing noise, which consists of unnecessary and frequently insignificant data points that may obscure major trends and insights, is crucial due to the difficulty associated with administering large volumes of data. To ensure that the resulting model accurately reflects the underlying patterns in the dataset, the critical task in this challenge is to achieve a balance between retaining valuable information and filtering out noise. Skipping to address this concern may notably hinder the efficacy of an investigation, resulting in tarnished predictive models and distorted analyses. In order to distinguish signal from noise in a manner that optimally advances the objectives of the study, the effective reduction of noise becomes a critical factor in the modeling of large-scale data, requiring the application of sophisticated techniques and methodologies. In pursuit of this objective, numerous approaches for dimensionality reduction and feature selection have been suggested (Khalid et al., 2014).

We can divide the approaches to dimensionality reduction and feature selection into two broad categories: feature selection and feature extraction. In feature selection, a subset of the original features is chosen, whereas in feature extraction, new features are generated by modifying the existing ones (Bolón-Canedo et al., 2015). In order to decrease the data's dimensionality, feature selection algorithms seek to discover and determine the most relevant features from the initial collection. Model generalizability, interpretability, and computing efficiency can all be enhanced in this way (Guo et al., 2017). Some approaches for selecting features include L1-regularized feature selection (Berahmand et al., 2020), a novel approach to limited feature selection (Omuya, 2021), and a clustering-based combined feature selection method (Annavarapu et al., 2021). Guo et al. (2017) and Alelyani et al. (2018) note the extensive usage of these methods in machine learning, pattern recognition, and data mining.

In contrast, feature extraction methods create new features by converting the existing ones. A popular feature extraction technique, Principal Components Analysis (PCA) seeks to generate new variables free of correlation by removing existing ones (Yu et al., 2016). Endalie and Tegegne (2021) cite Local Feature Discriminant Projection as another method that attempts to decrease dimensionality while maintaining the discriminative information in the data. In addition, there are techniques that reduce dimensions by combining feature extraction with feature selection. For instance, Liu et al. (2016) suggested a hybrid dimension reduction method that combines feature extraction and feature selection to improve classification accuracy. To further accomplish the simultaneous dimension reduction across several data kinds while performing feature selection independently for each data type, a method known as integrative and regularized generative topographic mapping (irGTM) was established.

Within the domain of feature selection and dimensionality reduction, the Boruta method has arisen as a highly advantageous expand to the current methodologies. In contrast to conventional feature selection algorithms which depend on statistical metrics, Boruta functions as a wrapper method, harnessing the capabilities of random forests to ascertain the significance of individual features within a given dataset (Kursa et al., 2010). Research in the modern era is tackling the problems of information overload and computational complexity, and the Boruta approach is useful for dealing with big and complicated datasets. When it comes to optimizing feature selection and dimensionality reduction

processes in the larger context of data analysis and predictive modeling, Boruta is a powerful and versatile technique that is leading the way.

The importance of careful feature selection in improving data analysis is highlighted by the several dimensionality reduction and feature selection approaches discussed in the related work section. Methods ranging from L1-regularized feature selection and clustering-based approaches to PCA, Local Feature Discriminant Projection, and hybrid methods that combine extraction and selection all have their place in extracting useful information from large datasets. The Boruta approach, which harnesses the power of random forests to improve feature detection, introduces a dynamic layer to this scene. It is becoming more clear how important feature selection is as we move through the ever-growing world of data analytics. Not only does this help with better model accuracy, but it also solves problems with computational complexity and information overload by allowing you to identify and remember the most important variables. Researchers and innovators in many domains, including data mining, pattern recognition, and machine learning, rely on meticulous attribute curation as a key component in their quest for data-driven insights that are more efficient, interpretable, and impactful (Chandrashekar & Sahin, 2014).

Method

The methodological approach utilized in this study revolves around the strategic selection of features, with the goal of improving the operational efficiency of a service that predicts the success of campaigns. We use a wide variety of feature selection and dimensionality reduction strategies in our process since we know that characteristics are very important for campaign predicts in the service. To improve the prediction model and make sure it works as good as it can, the main goal is to extract the most important and useful qualities from the original information. This approach to methodology is in line with the overarching objective of reducing the difficulties caused by computing complexity, enormous data quantities, and the possibility of noise introduction. Our goal in methodically choosing qualities is twofold: first, to improve the campaign performance prediction service's accuracy and efficacy; second, to add to the conversation about how to optimize data-driven services for CRM.

To achieve feature selection for optimizing the predictive model of campaign performance, we employed a synergistic approach utilizing the Random Forest algorithm in conjunction with the Boruta method. The random forest algorithm, first proposed by Breiman in 2001, was obtained due to the development and optimization of the random decision forest approach proposed by Ho in 1995 (Breiman, 2001; Hastie et al., 2009; Ho, 1995). In this work, we used the Boruta approach for feature selection, which works as an ensemble learning-based wrapper like the random forest classification algorithm proposed by Kursa and Rudniki in 2010. The Boruta approach determines the features to be included in the study by using sub-feature groups of randomly selected features, similar to the working principle of the random forest algorithm. The Boruta approach uses the Z-score, which is calculated by dividing the average accuracy loss among trees in the forest by the standard deviation. Murphy and his colleagues achieved statistically significant classification accuracy by using only the top 10% of features in random forest-based feature selection applications (Kursa & Rudnicki, 2010; McNally et al., 2018; Maxwell et al., 2018; Murphy et al., 2010).

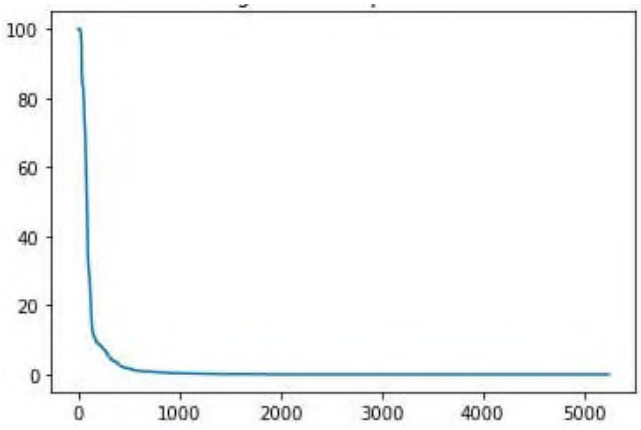
The Next4biz CRM software platform incorporates a functionality that enables the easy distribution of campaign notifications to existing or potential customers via email. The database keeps account of when consumers open campaign e-mails sent by businesses using the Next4biz CRM, as well as when customers open the campaign e-mails and click on the links therein. One more feature of Next4biz CRM that helps with campaign notifications is the automatic filtering method. This system allows businesses utilizing Next4biz CRM to send marketing messages to specific demographics. We utilized a PostgreSQL

database query to compile the filters and other descriptive aspects of the campaigns that Next4biz had previously delivered to customers and prospects through the Next4biz CRM software. We imported the data into Python and used the Pandas data frame structure to do analysis and preprocessing. The enormous amount of data presented significant challenges, so we preferred to perform a preliminary study first.

Data from 665 customers who clicked on the campaign links and 665 customers who did not click on the campaign links were incorporated into the set of criteria of this pilot study. Users were selected at random for the sample. Next4biz CRM's PostgreSQL database is used to store the tags utilized in the distribution of campaign notifications. The tags are organized in a JSONB format and a list structure. To parse the identifiers in this JSONB format, we developed a specialized Python parser. Through the utilization of this parser, we cyclically transformed each campaign's tag content into a fresh feature in binary format. We obtained a data set with 1330 rows and 5240 columns after converting the filters in the campaigns we sent to these individuals into attributes. We illustrated in Figure 1 the distribution of the occupancy rate percentage values for the campaign filters.

Figure 1

Percentage distribution of occupancy rates of campaign filters.



The analysis of Figure 1 revealed that a considerable number of features have values of zero or one. The features themselves have been impacted by the data sparsity problem in this particular case. Features that lack internal variation are currently incapable of providing a substantial level of explanation for the class. To make sure these superfluous features weren't affecting the classifier, we decided to run a feature selection study. In this approach, features that aren't useful to the classifier or are redundant will be filtered out by the feature selection algorithm. With this application, we intended to acquire a relatively small, noise-free dataset that had more information about the class. For our feature selection study, we decided for BorutaPy, a stable Python library.

Compiling all campaign submission lines after cyclically parsing the identifiers of each submission required a substantial amount of computing power. Using the big data libraries PySpark and Dask, we stored the final data as a CSV file at this phase, as the traditional Pandas data frame structure was deemed inadequate. The dataset grew by more than one hundred gigabytes when every campaign filter was transformed into a feature.

Results

Our classification analysis on this dataset utilizing the random forest algorithm resulted in an F-score of 0.58 and a success rate of 57.14%. We saw that these findings fell short of what is needed for the prediction model to be used operationally, but they did achieve the 50% success rate for two-class classifications, which is considered random. To enhance the outcomes derived from the research dataset, a feature selection study was executed utilizing the Boruta algorithm and the BorutaPy library, which was developed for the Python programming language and utilized by this algorithm. The objective was to eliminate features from the study that possessed a low explanatory value (Kurska and Rudnicki (2010)). Out of a total of 5440 features, the Boruta algorithm chose nine through 100 iterations. The random forest algorithm was utilized in our classification study incorporating the nine features under consideration. The achieved classification success rate was 59.14%, with an F-score of 0.59. The classification results were presented in Table 1.

Table 1

Feature Selection Impact on Prediction Performance

	Feature Count	Accuracy	F1
All features	5240	57.14%	0.58
Features selected by Boruta	9	59.14%	0.59

Feature Count: feature count of the dataset, Accuracy: Classification accuracy, F1: F1 score of classification

The analysis of Table 1 revealed that the prediction model achieved marginally higher accuracy and F1 Score values (albeit at a low level) in the classification study utilizing the feature subset obtained via the Boruta feature selection method. This improvement can be attributed to the elimination of irrelevant and irrelevant features. The results of this pilot application for feature subset selection demonstrate that employing Boruta feature subset selection is a logical approach to decrease the size of our data set by more than 100 gigabytes. We accordingly determined that our restricted computer capabilities are adequate to accomplish our objectives.

Discussion

Main Findings

The implementation of an effective predictive model for campaign notifications in the Next4biz CRM software represents an important improvement in the utilization of analytics driven by artificial intelligence to enhance customer relationship management. The tuning of the predictive model was significantly enhanced through the implementation of feature selection, which resulted in observable improvements in classification accuracy and F-score values. Significantly, the classification accuracies of our study, which were conducted on a balanced and randomly selected sample, ranged from 57.14% to 59.14%. This represents a notable improvement over the established random success level of 50% for two-class classification studies. The results of this study indicate that the meticulous selection of features via the Boruta algorithm significantly enhanced the predictive capability of the model. Nevertheless, it is critical to recognize that the achieved classification accuracies might not meet the standards for immediate productization, as evaluated by the Next4biz CRM team. Notwithstanding this, our findings establish an encouraging groundwork for subsequent pursuits, emphasizing the possibility of improved predictive performance by integrating a wider range of instances and discovering unique explanatory characteristics.

Expanding upon these discoveries, the assessment conducted by the customer relationship management team at Next4biz emphasizes the necessity for additional improvement in order to adhere to productization standards. The marginally improved classification accuracies indicate that although feature selection has helped improve the model, more advanced techniques or the incorporation of supplementary data are still required to attain the intended degree of predictive efficacy. It is crucial to recognise that further research, supplemented with a larger dataset and innovative explanatory characteristics, could potentially produce satisfactory outcomes. This observation draws attention to the dynamic nature of customer relationship management and highlights the iterative and adaptive process necessary to continuously improve the precision and utility of AI-powered analytics in predictive modeling.

Threats To Validity

This study utilizes a holistic strategy that incorporates the Random Forest and Boruta algorithms in an effort to enhance predictive models for campaign performance within the Next4biz CRM software. It is imperative that we evaluate the robustness and generalizability of our findings as we explore the internal and external validity considerations. To ensure the accuracy of our findings, we conduct an internal evaluation of our algorithms' sensitivity and potential sampling methodology biases. Examining the potential impact of unconsidered external variables on the predictions generated by our model, the constraints arising from the restricted range of features utilized, and the difficulties in generalizing our results to the entire CRM domain are all aspects addressed externally. The objective of this methodical assessment is to furnish a thorough comprehension of the soundness of our approach to selecting attributes and the consequences that this hold for customer relationship management predictive modeling (Baldwin, 2018).

Internal Validity

The reliability of our results might be affected due to the nature of the dataset utilized in this research. Potential sampling bias may have been introduced due to the random selection of 665 consumers who clicked on campaign links and an equal number who did not. As a result, the applicability of our findings to a larger population may be limited. In particular, Random Forest and Boruta, the implementation of machine learning algorithms, introduces the possibility of algorithmic sensitivity. The performance of these models might be influenced by the particular attributes of the dataset, and inconsistency in algorithmic hyperparameters or initial conditions might affect the validity and applicability of our findings.

The Boruta algorithm's iterative process, combined with the utilization of random forest classifications and multiple feature selections, gives rise to concerns regarding overfitting and model complexity. The primary objective of the Boruta algorithm is to improve feature selection through the identification of significant attributes. However, there is a potential drawback in that the model's performance on novel, unseen data could be compromised due to overfitting to the specific characteristics of the training dataset.

External Validity

The Influence of External Factors on classification success external variables not taken into consideration in our analysis might impact the quality of the classification study. Changes in campaign strategies, market dynamics, or consumer behavior may have an effect on the predictive capability of our model as time passes. Moreover, the constantly changing characteristics of the digital environment

might introduce unanticipated factors that are absent from the dataset, thereby compromising the overall accuracy of our prognostic model.

The Boruta algorithm's final classification study comprised a restricted scope of features. Although nine features were chosen, it is still possible that critical features that are essential for predicting campaign performance were overlooked. A potential risk to the accuracy of our model's prediction is the challenges involved in accurately and exhaustively representing the intricate relationship between customer behavior and campaign success.

In terms of generalizability to other CRM systems, the results obtained from this research are unique to the Next4biz CRM platform and the dataset it is linked to. The generalizability of these findings to a wider CRM context may be limited by variations in data structures, feature significance, and algorithmic performance, which could make extrapolating these results to other CRM systems difficult.

Conclusion

The findings of this research demonstrate the significant impact that feature selection has on improving the efficacy of prediction models utilized in the Next4biz CRM software to predict campaign success. Major improvements were made in classification accuracy and F-score values through the methodical exclusion of irrelevant and low-explanatory features. This underscores the efficacy of the Boruta algorithm in discerning the most important features, consequently enhancing the model's predictive capability. Progress toward better prediction models will be a top priority going forward. Subsequent investigations will examine a wide range of methodology for selecting features, encompassing approaches that rely on correlation, consistency, information gain, and gain rate, all in an effort to enhance the precision of predictions. Furthermore, our trajectory encompasses investigations into feature extraction, applications of dimension reduction, and supplementary methods for feature selection. By pursuing these approaches, our intention is to not only expand upon the accomplishments of this research but also establish a precedent for more resilient, flexible, and precise prognostic models in the ever-changing domain of customer relationship management.

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Chapter 11

Fostering a Self-Regulated and Collaborative Learning Environment: Employee Attitudes Towards the Benefits of Social Media on E-Learning Platforms in Remote Work Settings

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Abstract

Employees working remotely require a self-regulated and collaborative learning environment akin to that of traditional office settings. The integration of social media on e-learning platforms can facilitate the creation of such an environment.

This study examines the attitudes of employees working from home regarding the advantages of social media features integrated into e-learning platforms. It aims to understand how these features influence self-regulated and collaborative learning in a remote work context. To investigate employees' perceptions of the benefits of social media in this context, a quantitative research study was conducted. This study employed a survey to assess how social media tools on e-learning platforms contribute to fostering a self-regulated and collaborative learning environment among remote employees. The responses were collected through a structured questionnaire. The research sample included participants from diverse professional backgrounds.

The findings provide insights into employees' perceptions of how social media enhances their e-learning experience, including aspects such as idea exchange, collaborative learning environments, and the identification of educational needs and goals.

Keywords E-learning · learning environment · social media · collaboration

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Introduction

With the rise of technology-driven education, e-learning has become an integral part of organizational training and development. E-learning encompasses a broad array of electronically delivered learning tools, from online courses and virtual classrooms to interactive simulations and collaborative platforms. While the benefits of e-learning are widely acknowledged by companies aiming to improve accessibility and reduce costs, the employees' perception of these platforms significantly influences the effectiveness and acceptance of e-learning initiatives (Syed & Mohd Abdul, 2023). With the ongoing digitalization, work-from-home model has been increasingly adopted by numerous institutions and workplaces. The COVID-19 pandemic significantly accelerated this transition, supported by advancements in digital technologies. Nonetheless, working from home introduces a new set of challenges for employees, such as difficulty in balancing home and work life, feelings of isolation, and communication challenges.

This shift has underscored the importance of adopting digital communication software to facilitate collaboration, eliminating the necessity for employees to commute to physical office spaces and thereby increasing physical distance from colleagues (Haliburton & Schmidt, 2020). Consequently, employees working remotely may find themselves disconnected from the collaborative and socially interactive environments typically present in office settings. It is therefore essential for remote employees to develop their skills and adaptability to benefit fully from future office-based work environments.

Social media platforms can be instrumental in creating self-regulated and collaborative learning environments. The rapid integration of social media into the business sector, alongside growing interest in its potential applications in education, highlights its significance. Social media tools offer learners novel opportunities for independent research and work (Liu, 2010). Moreover, the proliferation of the Internet and advancements in educational technologies have substantially increased the availability of e-learning resources (Ruiz et al., 2006). Through these platforms, remote employees can continue their professional development, stay updated with current industry trends, and acquire knowledge across various disciplines.

The purpose of this study is to examine the attitudes of employees working from home towards the use of social media and e-learning platforms in fostering self-regulated and collaborative learning environments. Specifically, the study seeks to answer the question: "What are the attitudes of participants towards self-regulated and collaborative learning environments facilitated by the features and benefits of social media on e-learning platforms?"

E-Learning

With the advancements in digitalization, e-learning has become a prevalent method for conducting educational activities. E-learning is an internet-based system that leverages internet technology to design, implement, monitor, support, and enhance learning, significantly improving the efficiency of educational processes (Gunawan et al., 2018). It is anticipated that e-learning will become a primary mode of education in the 21st century, offering advantages such as diversity, assessment capabilities, and flexibility (Gunawan et al., 2018).

Learning content can be delivered through various systems and settings; however, it often lacks the dynamic interaction found in live classes (Mathivanan et al., 2021). Technologies and social media are essential for facilitating collaborative interaction in e-learning environments. These tools help in the generation and organization of ideas, the construction of knowledge, and the fostering of intellectual collaboration (Ak et al., 2020). E-learning also includes educational materials available on open-source platforms. For example, learners can easily access and enroll in free e-learning sites, with platforms

like Udemy and Coursera providing free educational content on life skills or various subjects through video-based lessons (Susanto et al., 2021). Furthermore, self-regulation skills are crucial for learners to successfully engage in e-learning. The transition to e-learning is more manageable for learners who possess self-regulation abilities, as they can navigate e-learning processes independently, utilizing self-control skills without needing direct instruction (Thomas, 2021).

Social Media and Social Learning

The advancement of digitalization has led to the widespread adoption of e-learning as a mode of delivering educational activities. E-learning, an internet-based learning system, utilizes internet technology to design, implement, monitor, support, and enhance learning, thereby significantly improving the efficiency and effectiveness of educational processes. As we progress further into the 21st century, e-learning is expected to become a dominant educational modality, offering distinct advantages such as content variety, assessment capabilities, and flexibility (Gunawan et al., 2018; Lee et al., 2011).

While learning content can be distributed through various systems and settings, it often lacks the interactive experience characteristic of live classroom settings (Mathivanan et al., 2021). The integration of technologies and social media is critical in facilitating collaborative interactions within e-learning environments. These tools support the generation and organization of ideas, the construction of knowledge, and the convergence of intellectual contributions (Mnkandla & Minnaar, 2017). E-learning also encompasses educational materials available on open-source platforms. For example, learners can freely access and enroll in courses on platforms such as Udemy and Coursera, which provide instructional content on a wide range of topics, including soft skills, through video-based materials (Susanto et al., 2021).

Moreover, self-regulation skills are essential for learners to effectively engage in e-learning. Learners with strong self-regulation abilities find the transition to e-learning more manageable, as they can navigate these processes independently, utilizing their self-control skills without requiring direct instructional support (Thomas, 2021).

Learning Experience Platform (LXP)

Learning Experience Platform (LXP) is an advanced e-learning platform that offers a diverse array of educational content to learners. LXPs provide access to various e-learning materials, enabling learners to access resources tailored to their specific needs and support the development of their professional competencies. LXPs integrate functionalities akin to those found on social media platforms, thereby creating virtual learning environments (Cockrill, 2021). This integration allows learners to generate and share their own content, engage with peers through comments, and provide feedback on training materials. Such interactions promote a “social learning environment” and facilitate increased collaboration among learners.

The simplicity of access and communication features in LXPs ensure a contemporary, social, and interactive learning experience (Cockrill, 2021). Furthermore, with advancements in technology, LXPs are increasingly adopting sophisticated technologies such as artificial intelligence. The utilization of AI in these platforms can provide learners with personalized recommendations and guidance based on their activities, thus enhancing the learning experience. This technological integration supports the development of learners' self-regulation skills, empowering them to take greater control over their educational journeys.

Employees' Perception Towards E-Learning

E-learning has transformed the landscape of professional development in organizations, offering a flexible, scalable, and often cost-effective alternative to traditional learning methods. As organizations increasingly adopt e-learning solutions, understanding employees' perceptions of these digital platforms becomes crucial to optimizing their design, implementation, and efficacy. Employees' perceptions of e-learning are generally mixed, reflecting both advantages and challenges associated with this mode of learning. Many employees appreciate the flexibility and convenience that e-learning offers, allowing them to engage with training materials at their own pace and on their own schedule, which can be especially valuable for balancing work and personal responsibilities. However, some employees find e-learning isolating and miss the interactive, social elements of traditional in-person training. Additionally, navigating technical challenges and maintaining self-motivation can be obstacles that affect their engagement and satisfaction. It is possible to group these perceptions (Agrawal et al., 2017):

Positive Perceptions:

- **Flexibility**: Many employees appreciate the ability to learn at their own pace and on their own schedule.
- **Accessibility**: E-learning allows employees to access materials from anywhere, making it easier to balance work, learning, and personal life.
- **Cost-Effectiveness**: It can be more affordable than in-person training, both for employees and organizations.

Negative Perceptions:

- **Lack of Interaction**: Some employees miss the face-to-face interaction that traditional learning provides, which can make e-learning feel isolating.
- **Self-Motivation**: E-learning requires a higher level of self-discipline, which some employees may find challenging.
- **Technical Issues**: Connectivity and platform-related issues can hinder the learning experience.

Mixed Reactions:

- **Engagement**: Some employees find e-learning engaging, especially with multimedia and interactive content, while others find it difficult to stay focused.

While e-learning provides a cost-effective and accessible solution for professional development, its success depends on addressing employees' diverse needs and preferences to foster a positive learning experience.

Materials and Method

Research Design

Employees working remotely frequently encounter challenges in establishing a collaborative and socially interactive learning environment comparable to that of an office setting (Arrawal et al., 2017). To investigate the attitudes of remote employees towards the utilization of social media features on e-learning platforms for promoting self-regulated and collaborative learning environments, a quantitative research design has been developed. This study will employ a survey methodology to evaluate

employees' perceptions and attitudes regarding the effectiveness of e-learning platforms in facilitating such learning environments.

Sample

The study's population consists of employees working remotely in Turkey. A voluntary response sampling method was utilized to select participants, allowing individuals to opt into the study based on their own willingness. Respondents who were willingly participated and responded to the questionnaire comprised 35 and were from diverse companies operating in Turkey. The sample was chosen by searching from their LinkedIn profiles.

The final sample comprised 35 employees, categorized by age groups as follows: 9 participants 20-29; 10 participants 30-39; 12 participants 40-49; and 4 participants 50 and above. The sample includes 8 female and 27 male participants. The respondents' characteristics details are shown in Table 1.

Table 1

Demographic Characteristics of the Respondents

Category	Group	Frequency (N=35)	Percentage
Gender	Male	27	77.1
	Female	8	22.9
Age	20-29	9	25.7
	30-39	10	28.6
	40-49	12	34.3
	50 and above	4	11.4

This research is conducted with a focus on examining attitudes towards e-learning platforms without considering the differences in socioeconomic status (SES) or gender.

Instrument

The data were collected through a survey to assess employees' attitudes and perceptions regarding the use of e-learning platforms for collaborative and self-regulated learning environments while working from home. The questionnaire consists of 17 close-ended, multiple-choice questions based on Likert's 5-point scale.

The questionnaire is self-developed by the researchers based on the study's objectives. It was prepared on Google forms and circulated online. After that, a pilot study was made with a small sample to check the reliability of the questionnaire. The final instrument was refined with the assistance of two experts in educational technology to ensure its validity and reliability.

Procedure

Participants in this study were employees from diverse occupations who volunteered to participate. The sample comprised individuals from various sectors, including finance (e.g., bankers and financial advisors), information technology (e.g., computer engineers, data processing specialists, computer technicians, software developers, and software engineers), and other roles such as economists, electronic engineers, instructors, graphic designers, junior developers, architects, customer representatives, customer service managers, teachers, and sales managers.

The survey was administered online and included an introductory section with informative text and a consent form. Data were concurrently collected from employees working remotely and those utilizing

a hybrid work model. Data from employees working exclusively on-site were excluded from the study. The collected data were subsequently analyzed with IBM SPSS software to assess and compare the attitudes of employees from various occupations regarding the benefits of social media features on e-learning platforms. Since the sample size is low only descriptive statistics were used.

Results and Discussion

The aim of this study was to investigate the attitudes of employees working from home regarding the benefits of social media features on e-learning platforms. The survey was designed to explore employees' perceptions of how these platforms contribute to self-regulated and collaborative learning environments. Considering the research question of this study, “what are the attitudes of participants towards self-regulated and collaborative learning environments facilitated by the features and benefits of social media on e-learning platforms”, the results can be outlined in four categories as mentioned below.

Using E-Learning Platforms

The findings indicate that 91.2% of participants use e-learning platforms to manage both online and in-class training within their organizations. Of these, 67.6% agreed or strongly agreed that e-learning platforms are effective in accessing up-to-date information relevant to their professional fields. Additionally, 58.8% of participants believe that social media facilitates communication and information sharing with other users.

Social Media Effect

In terms of the effects of social media on collaborative learning environments, more than half of the respondents indicated that social media supports feedback, commentary, and idea-sharing. Specifically, 41.2% of participants agreed that social media enhances collaborative work, while 32.4% disagreed, and 26.5% were neutral regarding its impact on collaboration. Over half of the participants reported that e-learning platforms assist in learning through interaction with colleagues. According to the survey, 61.8% of employees believe that e-learning platforms with social media features promote the exchange of professional ideas, and 58.8% feel these platforms foster a collaborative learning environment.

Self-Regulated Learning

Furthermore, 70.6% of participants agreed that e-learning platforms enable them to manage their learning processes effectively. Regarding the use of social media for planning educational activities, 50% agreed, 26.5% disagreed, and 23.5% remained neutral. Additionally, 61.8% of participants perceived that e-learning platforms with social media features contribute to achieving educational goals, and 64.7% felt these platforms help in identifying their educational needs.

Collaborative Learning

The study also found that 73.5% of employees prefer platforms that allow active engagement and interaction with teams. More than half of the respondents expressed interest in sharing events with colleagues and recommending preferred training sessions. Moreover, 61.8% of participants were interested in creating and sharing professional training content with peers, while 14.7% were neutral on this aspect. Lastly, 67.6% of participants favored selecting elective training over mandatory courses.

Conclusion

Employees' perceptions of e-learning are shaped by various factors, including the flexibility, cost-effectiveness, and engagement level of digital platforms. While e-learning offers numerous advantages, it also presents challenges, particularly concerning social interaction, motivation, and technical issues. Organizations can address these challenges by fostering a supportive environment, enhancing interactivity, and implementing blended learning approaches. By understanding and responding to employees' perceptions, organizations can optimize e-learning to become an effective and valued component of professional development.

The study indicates that employees utilize e-learning platforms to stay updated with current courses, acquire job-related knowledge, and enhance their professional expertise, while leveraging social media to exchange ideas and communicate with their colleagues. As Dabbagh and Kitsantas (2012) and Gunawan et al. (2018) mentioned, when remote employees engage with e-learning platforms that incorporate social media features, they foster a working environment that supports both collaboration and self-regulation. These platforms facilitate the exchange of ideas, promote collaborative learning, and assist in identifying and addressing educational needs and goals (Moreno et al., 2013). The findings of this study fully comply with this statement.

Employee attitudes towards the integration of social media on e-learning platforms in remote work settings are generally positive, as social media tools facilitate communication, engagement, and collaboration. In a remote work environment, employees often feel isolated from their colleagues, which can hinder the learning process. Social media features, such as discussion boards, group chats, and interactive comments, allow employees to connect, share insights, and support one another, creating a more engaging and interactive learning experience. Many employees appreciate the informal and dynamic nature of social media, which contrasts with the structured, often impersonal nature of traditional e-learning platforms. Additionally, social media elements on e-learning platforms help to build a sense of community, fostering peer learning and collective problem-solving, which are essential for remote teams. However, while many employees view these features as beneficial, some may find them distracting or may struggle to balance the social aspects of learning with focused study time. In general, the integration of social media on e-learning platforms in remote work settings is perceived as a valuable addition, promoting connection and enhancing the overall learning experience.

Limitations of the Study

This study has two types of limitation: the first limitation is related to sample size, geographical location and the possibility of extending fieldwork over time; the second limitation is about data collection. This study was conducted to employees working in Turkey. Since the data were collected online there may be some insufficient responses. Data were collected from employees working remotely and those utilizing a hybrid work model. Data from employees working exclusively on-site were excluded from the study. By using additional qualitative techniques, the results of this study could be strengthened.

Further Research

There is a large space for further research to identify some other factors, their effectiveness and their adaption by a large number of employees and organizations. This type of study can also be conducted by using qualitative techniques to get more insights from the participants. Also, conducting additional longitudinal surveys can be planned, as individuals' perceptions and preferences may vary over time as they gain more experience.

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Chapter 12

Learning Cultural Assets of Van City with Location-Based Augmented Reality Mobile Game

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Abstract

Mobile learning is a form of learning that enables access to content and communication with other learners without being tied to a location. Mobile learning environments have shown that education can be possible without being in a fixed place with mobile devices. Research results have shown that mobile learning has a statistically significant effect on students' academic achievement, and students supported by mobile learning achieve higher success than students who receive only face-to-face education. One of these application methods that can be used on mobile devices is augmented reality technology. Augmented reality is a field of study that covers the combination of the real world and computer-generated data such as audio, video, graphics, location information. In this study, digital game-based learning method was used. With a location-based application used in mobile devices, results were obtained and presented with a mobile augmented reality game prepared based on a scenario for those who want to learn the culture of any city through a location-based application used on mobile devices. The mobile application was developed with the TaleBlazer game engine developed by the MIT Scheller Teacher Education Program laboratory. The developed game was applied to 14 students studying in a high school in Van. Qualitative and quantitative methods were used to evaluate the research data. In quantitative evaluation; Mean, standard deviation, percentage, frequency and t-test calculations were made. Themes and codes were created for qualitative evaluations. This game, developed to learn something about the culture of a city, has proven to be a good way to learn. According to the results obtained from those who participated in the game; It is understood that it helps them recognize the historical buildings of the city, helps them understand the real places and the nature of the city, the scenario is sufficiently descriptive, they enjoy the game, and it gives the participants a better idea about how virtual reality games played outside.

Keywords Augmented reality · game-based mobile learning · taleblazer

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Introduction

With the development of information and communication technologies, access to information is becoming easier. In this case, the information structure of the society, fast communication, constantly changing new technologies have been deemed necessary and have become a necessity in our lives (Karabulut, 2015). When information is accepted as a production element, a society in which the use of computer and communication technologies is essential in business and transactions such as processing and storing information is required (Sayın & Seferoğlu, 2016). The rapid spread of mobile technologies has also changed the way individuals interact with information and their environment. Smart devices such as phones, tablets and even watches are replacing computers and their capacities and speeds are increasing with each new model. Today, many different business areas from banking to health, from tourism to communication effectively use the internet and mobile technologies to increase efficiency in their business and offer their services through mobile technologies (Dağhan & Akkoyunlu, 2017).

The new generation, referred to as the digital generation or Generation Z, is predicted to differ from previous generations because they were born and raised in a digital age (Oblinger & Oblinger, 2005). Although the speculation that this generation possesses digital knowledge and skills without the need for extra education has been criticized (Somyürek & Karabulut, 2013), it is obvious that internet technologies and digital equipment are a part of daily life for the new generation (Kennedy et al., 2008). Therefore, it is thought that traditional learning methods and environments will not be sufficient to attract their attention as they did in previous generations.

Mobile technologies enable us to organize and direct our daily lives with the mobile applications we use during the day. One of these applications that can be used on mobile devices is augmented reality technology. Applications that enable the use of augmented reality technology on mobile devices are used in various fields such as advertising, manufacturing industry, health and education. Mobile augmented reality applications can also be used in the field of education with their two and three dimensional visual support, video playback, and interactive opportunities such as external web page connection.

Mobile applications are codes designed and implemented specifically for smartphones and tablet computers (Alastyr, 2022). Mobile applications, like mobile devices, are produced according to the people who will use these applications (Namlı, 2010). Since mobile applications can be produced in different ways according to the cultures, usage habits and usage purposes of the users, there may be more than one mobile application produced for the same purpose. Mobile technology devices such as portable and internet-connected iPads, laptops, tablets, and smartphones allow mobility and mobile learning, taking the learning-teaching process outside the traditional classroom walls. In the classroom, mobile learning provides both the learner and the teacher with flexible environments and new possibilities for interaction. Learners can access learning content from anywhere and anytime through their mobile devices, thus eliminating physical limitations in learning environments (Dağhan & Akkoyunlu, 2017).

When mobile learning research is examined, it is seen that while the hardware features of mobile devices were at the forefront and expensive in the past years, today the effective use of mobile learning content, mobile learning design come to the forefront and many people use it as a communication tool (Kuşkonmaz, 2011). The small size of mobile learning devices has made it compulsory to present information in small groups, and the presentation of teaching subjects in the form of small piles, etc., which are frequently emphasized in information processing theory and other learning theories, has enabled the design criteria to be met (Uysal & Gazibey, 2010). Although the interest in mobile phones is very high in Turkey, it is not possible to say that the applications related to mobile learning have

reached a sufficient level due to high data service (such as mobile internet) fees and low perception levels of users towards mobile learning. Today, while studies on mobile learning are progressing at the academic level and in an experimental sense, some private companies have taken the studies on mobile learning one step further (Kuşkonmaz, 2011).According to the results of the research, it has been observed that mobile learning has a statistically significant effect on students' academic achievement, and students supported by mobile learning achieve higher success than students who receive only face-to-face education (Durak et al., 2017).

Game-based learning is an environment in which learning objectives are included in the game sections and students produce solutions to achieve these objectives (Malta, 2010). Game-based learning environments are created with certain problem scenarios. In game-based learning environments, students create their own problems, conduct research on these problems, communicate with their peers and solve the related problem as a result. One of the most important skills that students gain in game-based learning environments is the ability to critically evaluate the problems they frequently encounter in daily life. In this respect, gamification serves as a bridge between learning environments and learning (Palancı, 2019). Educational games are "software that enables students to learn course subjects or improve their problem-solving skills by using the game format." (Sayın & Seferoğlu, 2016). Game-based learning environments are game-based problem-based learning environments that are placed in specific problem scenarios (Demirel et al., 2003). They give the opportunity to fictionalize real-life events with realistic simulations away from dangers. By appealing to multiple sensory organs, they make learning more permanent. While providing all these, they entertain students in the process (Yağız, 2007). Kirriemuir and McFarlane (2004) state that educational games have some contributions to students. These are emphasized as important gains such as decision making, planning, communication and strategic thinking. On the other hand, Shaffer et al. (2005) argue that game-based learning environments create new social and cultural worlds and that this helps learning by combining thinking, social communication and technology.

Augmented reality (AR) technology is an environment where people interact with virtual objects placed on the real world environment through various applications. In augmented reality environments, virtual and real objects are combined and presented to users in harmony. In other words, augmented reality is a virtual reality application in which users interact with virtual objects while interacting with the real world without affecting the real world (Demirer & Erbaş, 2015). Although augmented reality technology has found computer-based use for years, it has recently started to be used on mobile devices with different applications developed recently. It can be said that the main reason for this situation is the cheapening and widespread use of mobile smart device technologies (Güngör & Kurt, 2014). In the literature review, it was seen that AR applications have become widespread in the field of education in recent years. The purposes of using AR in educational environments are grouped under the titles of "training, educational trip, curriculum complementary (supportive), games, guidance and promotion" (Çetinkaya & Akçay, 2013).The advantages offered by educational AR applications have encouraged researchers and instructors to work on integrating AR technology with educational environments (Küçük, 2015). In recent years, especially with the widespread use of mobile devices with internet access, the number of augmented reality applications on mobile devices and the number of research on this subject has been increasing.

In particular, the fact that mobile devices enable software development, have location determination systems (GPS, etc.), and have increased graphic display capabilities and memory capacities increases the usage areas of mobile devices considerably. These features have increased the usability of mobile devices and especially the applications of routing system design with location-based technology have become widespread (Selvi & Bildirici, 2011).

Digital game-based learning is an approach that facilitates learning in today's technology and positively affects students' motivation. For this method, researchers and educators say that "digital game-based learning is a pedagogical approach that increases students' participation in active learning situations where they need to use their knowledge and competencies in scenario-based problem solving and decision making" (Kiili, 2005; Gee, 2007; Prensky, 2001). The motivational effect of digital games, combined with their structure that allows "learning by doing", makes them attractive learning tools (Carenys & Moya, 2016).

In our study carried out in line with this preliminary information; in accordance with the digital game-based learning method, it is aimed to teach the historical places of a city with a permanent, fun and different perspective by using location-based application augmented reality application using mobile devices. The scenarios of the application were designed to teach the cultural assets of Van city.

Materials and Methods

In the study, digital game-based learning method, which is a computer-assisted learning approach, was used. Game learning scenarios were prepared. Afterwards, a game engine was chosen to code the scenarios. For this, the TaleBlazer game engine developed by the Massachusetts Institute of Technology (MIT) Scheller Teacher Education Program (STEP) laboratory was preferred. The reason for this preference is that it can also be used on the Android operating system among other game engines. The scenario was then coded in appropriate places on the game engine. After the digital game-based learning material was ready, the research population and sample were identified. The sample was told how to play the game. Afterwards, data were collected from the volunteers through the game feedback questionnaire and face-to-face interviews with the very triangulation method, and since the research sample consisted of 14 people, t-test was applied in the evaluation of the data. The data obtained are shared in this study.

Population and Sample

In this study, people who want to learn about the cultural assets of Van province constitute the population of the research. The designed game was explained by the researchers to 120 11th grade students studying in a high school in Van province and 26 people who were willing and want to play the game were reached. The participants were selected by taking into account the criteria that they should have basic English knowledge and a smartphone and that they should not have any restrictions in walking on foot. Twelve of the participants were excluded from the study because they did not complete the game, and 14 participants who completed the game constituted the sample of the study. Six men (42.9%) and eight women (57.1%) participated in the study. The average age of the participants was 18.36 years.

Data Collection

Questionnaire and interview methods were used to collect data. Data triangulation was used in the research. There are three different approaches commonly used in data triangulation. The first approach is to collect qualitative data first and then supplement it with quantitative data; the second approach is to use quantitative data as the main data source and then supplement it with qualitative data; and the third approach is to collect qualitative and quantitative data at the same time (Gay et al., 2006). In this study, data triangulation using the third approach was utilized by collecting qualitative and quantitative data at the same time.

The students' opinions about the game were obtained with a seven-point Likert-type game feedback questionnaire developed by Jan Mingfong (Mingfong, 2009), consisting of 16 items, ranging from

1 (Strongly Disagree) to 7 (Strongly Agree). The necessary permissions were obtained for the use of the questionnaire and the items were organized in accordance with the game content. At the editing stage, the questionnaire was finalized by taking the opinions of field experts whose second language is English and field experts from the History department. In the collection of interview data, for the game feedback scale, open-ended "Post-Game Short Answer Questions" consisting of 5 items prepared by taking expert opinion from 3 experts in the field were asked to the players.

TaleBlazer Game Engine

Developed by the MIT Scheller Teacher Education Program lab, TaleBlazer allows users to play and make their own location-based mobile games. By embedding games in the real world, AR games aim to immerse people in experiences that combine real landscapes and other aspects of the physical environment with additional digital information provided by smartphones. TaleBlazer is the latest augmented reality software platform developed in the STEP lab. TaleBlazer games are played in the real world. Players interact with virtual characters, objects and data as they move through their real location. TaleBlazer games can be played on most GPS-enabled Android and iOS smartphones. Once a game is downloaded to a smartphone, no internet connection is required to play the game (TaleBlazer, 2019).

The TaleBlazer editor is browser-based and does not require local installation. The TaleBlazer editor uses a visual blocks-based scripting language that helps users avoid syntax errors while facilitating the creation of rich interactivity. Users create accounts that allow them to save game files to the cloud, which can then be downloaded directly to a player's smartphone. TaleBlazer game designers can instantly access TaleBlazer games from any internet-connected computer (TaleBlazer, 2019). The TaleBlazer game engine used in the design of the game was used with the necessary permissions.

Game Scenario

This scenario was designed by the researchers. The scenario for the play titled "Van from the Cities":

"According to legend, on Akdamar Island, the largest island in Lake Van, lives the Armenian abbot Tuman and his beautiful daughter Tamara. A young man named Ahmet, who works as a shepherd in the villages on the opposite side of the island, falls in love with this beautiful girl. Tamara is also devoted to Ahmet with an unspeakable love. Ahmet swims to the island every night to see Tamara. Tamara waits for him in the dark with a lantern in her hand to give away her location. After a while, Tamara's father Tuman becomes aware of this and becomes very angry. In order to separate them, he first imprisons Tamara in the dungeon on the island and locks the door with a combination lock, then, on a stormy night, he goes down to the shore of the island with a lantern and makes sure that the young man reaches the shore with the lantern. In order to prevent Ahmet from reaching Tamara, Tuman locks Ahmet in a cage next to the church with a combination lock. He then takes a boat and hides these codes in historical places in Van province. On their way back to the island, a storm rages and Tuman's boat capsizes. Tuman dies there. Tamara and Ahmet are left in captivity..."

Volunteers' Implementation Process

According to the scenario, the player, who plays the role of a detective, is asked to go to the real locations of these passwords hidden in the historical places of Van city and find the passwords.

The player is directed in a certain order to 10 different points in the city of Van where historical buildings are located and within walking distance of each other. When the player arrives at these points, questions about the historical building (text, visuals, animation, audio, video, etc.) and information about the historical place are displayed on the screen. When the question is answered correctly, the

next historical point to be visited appears on the map. Thus, the game is completed by finding all the passwords in the game and fulfilling the role specified in the scenario.

In order to access the game from the TaleBlazer application installed on the mobile devices of the volunteers, the code of the game to be accessed is entered in the Game Code field and the game is accessed. The location-based augmented reality game prepared within the scope of the research was named "Van from the Cities". The game code "gglakri" was given to the game "Van from the Cities" by TaleBlazer. This code can be accessed by entering the "Game Code" field. The game interface image is shown in Figure 1.

Figure 1

TaleBlazer Game Engine App and Van from Cities Game Start Screen

When the game starts, the scenario of the game comes first. What the player needs to do is presented in the form of a scenario. The player who reads the script will start playing the game accordingly. After starting to play the game, the game scenario is loaded in the "History" area. The player can access the game scenario again whenever they need it. When the game starts, the places where the player needs to go, which are also given as hints, appear as dots on the map. When the game starts, there is only one point on the map representing a historical place where the player needs to go at that moment. At the same time, another point showing the player's actual location changes its position on the map depending on the player's movement. The points of the other historical sites appear in order after the active chapter has been passed. The player, who takes on the role of a detective in the scenario, goes to the first specified target in the game and enters the "ClueCode" field by finding the answer to the question there and provides the next task. The game scenario and the information of each chapter is stored in the History field and can be accessed at any time. Figure 2, Figure 3 and Figure 4 show screenshots of the game.

Figure 2
Scenario Area Figure

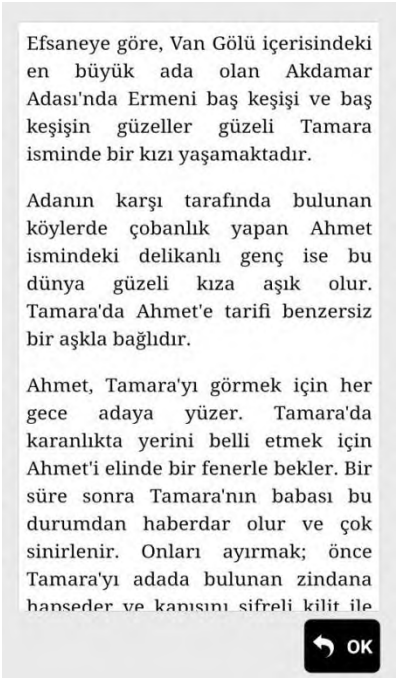

Figure 3
Map Area Figure

Figure 4
Player Area

Results and Discussion

The data obtained from the volunteers through the game feedback questionnaire are shown in Table 1.

Table 1
Game feedback survey results

Game feedback items	*Mean*	*SS*
I enjoyed playing the game Van from Cities.	6.00	1.56
I learned new things about the city of Van while playing the game.	6.50	0.65
I like to play outdoor reality-enhanced games more.	5.29	1.63
I felt the game was too easy.	4.14	1.56
I felt the game was too long.	3.64	1.64
Playing the game was a good way to learn about the city of Van.	6.64	0.84
Playing the game increased my curiosity about the history of the city of Van.	5.57	1.55
There was a lot of reading in the game.	4.07	2.16
There were times when I could compare the places around me with what I saw on my screen.	5.29	1.89
I enjoyed using my smartphone with my partner throughout the game.	5.36	1.69
I identified myself with the character in the game.	5.21	1.62
Playing the game gave me a better idea of how outdoor virtual reality games work.	6.00	1.10

Game feedback items	*Mean*	*SS*
The real locations in the game helped me understand the nature of the city of Van.	6.36	0.74
The game scenario was descriptive for me to play my role.	6.29	0.82
The game helped me to understand the historical buildings of the city of Van.	6.57	0.64
Playing this game helped me to learn about the places in the Old City of Van that I needed to know.	6.57	0.51

n: number, SS: standart deviation

When the answers given to the game feedback questionnaire are analyzed; The game was a good way to learn about the city of Van (Mean=6.64, SS=0.84), it helped to understand the historical buildings of the city of Van (Mean =6.57, SS=0.64), it was instructive about the places that should be known in the Old City of Van (Mean =6.57, SS=0.51), it taught something new about the city of Van (Mean =6.50, SS=0.65), The items with the highest mean scores in the questionnaire were that the real locations helped to understand the nature of the city (Mean =6.36, SS=0.74), the scenario was descriptive (Mean =6.29, SS=0.82), the game was enjoyable (Mean =6.00, SS=1.56) and it gave a better idea of how outdoor virtual reality games work (Mean =6.00, SS=1.10). At the same time, it is seen that the items such as the game being too long (Mean =3.64, SS=1.64), too much reading in the game (X=4.07, SS=2.16), and the game being easy (Mean =4.14, SS=1.56) are the items with the lowest averages in the survey.

According to the findings, it is understood that the volunteers are satisfied with being informed about the cultural assets of the city they live in. In addition, it is seen that they are satisfied with knowing where the cultural assets in the city are located, learning new information about them, and realizing them through the game learning method.

When the results obtained from the questions asked to the volunteers through interviews are examined, the answers given to the first question "What did you like about the game?" are shown in Table 2.

Table 2

Answers to the question "What did you like about the play?"

Volunteer Answers	*f*	%
The game is clear and simple	3	21.43
It is very good that it promotes the values of the province	4	28.57
Game is mobile (locally based)	5	35.71
It is very useful to teach the history of the province	8	57.14
Having an augmented reality game on a mobile device	14	100

f: frequency, %: percent

According to the data obtained from the volunteers; the fact that it is an augmented reality game on a mobile device was mentioned by 14 people, that it teaches the historical places of the province by 8 people, that the game is played by traveling by 5 people, that it teaches the values of the province by 4 people, and that the game is understandable and simple by 3 people. As can be seen, it is understood that the fact that learning with a mobile device and game motif attracted the volunteers' attention and contributed to learning.

The answers given to the second question are shown in Table 3.

Table 3
Answers to the question "What did you dislike about the game?"

Volunteer Answers	f	%
I'm tired of walking	1	7.14
I would have liked more information about the places visited in the game	4	28.57
There was nothing I didn't like about the game.	9	64.28

f: frequency, %: percent

According to the results obtained from the volunteers; 9 people stated that there was nothing they disliked in the game, 4 people stated that there should be more information about the places visited, and 1 person stated that they got tired because of walking. In general, it is understood that the game is liked.

The answers given to the third question are shown in Table 4.

Table 4
The answers to the question "What do you think about the promotion of the historical places of the city while playing this game?"

Volunteer Answers	f	%
It would be better if more detailed information was given in the places visited	1	7.14
A very nice app for tourists and to learn about the province	4	28.57
I liked the presentation of the important places of the province	9	64.28
I enjoyed visiting historical sites	9	64.28

f: frequency, %: percent

According to the results of the findings obtained from the volunteers; 9 people stated that the game was welcomed to visit historical places, 9 people stated that it introduced the important places of the province, 4 people stated that it was a good practice to get to know a province and to introduce that province to tourists. In general, it is understood that the game is thought to contribute to the promotion of the cultural assets of the city.

The answers given to the fourth question are shown in Table 5.

Table 5
The answers to the question "What do you think about learning the historical places you should know in the province with the game Van from the cities?"

Volunteer Answers	f	%
I liked the game very much because it serves this purpose	3	21.43
Thanks to this game, we learned that the places we thought we knew in Van province were not actually correct.	4	28.57
I like that it is both permanent and explained in a simple way	7	50.00
I liked learning about historical places by traveling around.	13	92.82

f: frequency, %: percent

According to the results of the findings obtained from the volunteers; 13 people stated that it was welcomed in terms of teaching historical places by taking them on a tour, 7 people stated that it taught

in a simple and permanent way, 4 people stated that they thought they knew the historical places in the province and that they actually learned that they did not know correctly thanks to the game, and 3 people stated that the game was liked because it served its purpose. It is seen that volunteers generally expressed positive opinions.

The answers to the fifth question are shown in Table 6.

Table 6

Answers to the question "How did it make you feel to play the role of a detective?"

Volunteer Answers	*f*	%
It was beautiful and mysterious	6	42.84
I impatiently tried to complete the game	6	42.84
It was motivating	7	50.00
It was exciting	11	78.54

f: frequency, %: percent

According to the results of the findings obtained from the volunteers, the feelings of being in the role of a detective in the game; 11 people found it exciting, 7 people found it motivating, 6 people stated that they could not wait to complete the game and 6 people stated that it was very beautiful and mysterious.

Conclusion

In this study, a scenario-based mobile game was designed for those who want to get to know the historical places of a city with a location-based application to be used on mobile devices by considering the game-based learning method.

According to the survey and interview results obtained after the game; it was concluded that the game was a good way to learn about the city, it helped to understand the historical structures of the city, it taught something new about the city, the real places helped to understand the nature of the city, the scenario was sufficiently descriptive, the game was enjoyed and it gave a better idea about how virtual reality games played outside work. From this point of view, it was concluded that the digital educational game prepared was liked, received positive feedback for the purpose, and could be used for educational purposes. In addition, it was concluded that it was welcomed in terms of being an augmented reality game on a smartphone, teaching the historical values of the province, teaching by visiting historical places, teaching in a simple and permanent way. It was concluded that being in the role of a detective in the scenario motivated the participants, was exciting and they were impatient to complete the game. Based on these results, it can be said that being in the role of a detective in the scenario excited the players and was effective in fulfilling the role given by focusing on the game. With these results, location-based augmented reality mobile game can be used as a scenario-based augmented reality mobile game to learn the historical values of a city in a permanent way.

According to Demirer and Erbaş's (2015) study, mobile augmented reality applications have features that can be used in areas such as mathematics and science for concretization, virtual laboratory activities and out-of-school student activities. In addition, it can be used to visit geographical and historical areas with location-based features in the field of social sciences, and to make historical places, sculptures and paintings interactive with historical images.

In order to achieve maximum success from mobile devices in education, the technology should work reliably and smoothly (Kukulska-Hulme, 2005). Since the use of mobile devices in education has a positive effect on learning, augmented reality applications used in mobile devices can be used more.

Location-based and scenario-based applications can be used more often in education, as they put the player in a certain role and make them more willing and focused on learning. More permanent learning can be realized with these and similar games, rather than explaining historical places in lessons with a straight narrative method.

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Chapter 13

Machine Learning Step by Step: From Data to Interface

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Abstract

Interest in the field of artificial intelligence is increasing day by day. Machine learning, a subfield of artificial intelligence, is also affected by this interest. It is seen that machine learning algorithms are frequently used in the process of transforming data into valuable information. These algorithms are applied to the data set according to methods such as CRISP-DM, Database information discovery process. As a result of these applications, a model is generally obtained and interpreted and shared in the literature. The results of this model should be used by people who do not know the programming language and an interface should be prepared for ease of use. In this study, it is aimed to demonstrate the application process of a developed machine learning model using an example data set. For this purpose, the "Titanic" data set, which everyone can easily access and use, was used. The machine learning model was developed using the Python programming language and related libraries, and then the interface and distribution of the developed model was carried out. Github, Streamlit, and Heroku platforms were used to distribute the model. It is recommended to experience the entire process from data to interface by applying this book chapter step by step. We hope it will be useful for beginners in the field of data science for a human-centered future.

Keywords Machine learning · data science · titanic dataset · interface · python

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Introduction

In data mining process models, the last stage of the process is defined as implementing the developed model. For example, the CRISP_DM process model; is carried out in 6 stages: Defining the problem - Data Understanding - Data Preprocessing - Modeling - Evaluation of the model - Implementation of the model (Chapman et al., 2000).

Despite many resources in the literature for the first 5 stages of machine learning processes, there seem to be insufficient resources for the "implementation of the model" phase. Different methods are used to deploy machine learning models. Implementation phase; Flask (Flask, 2023; Grinberg, 2018), PyCharm (PyCharm, 2023), ML.Net (Microsoft, 2023), etc. It can be carried out manually using IDE software, or in MLOps (Machine Learning Operations) systems developed to make workflows simple, portable, and scalable by providing ready-made infrastructures for machine learning models.

MLOps platforms are applications used to facilitate the difficulties encountered in the machine learning life cycle and provide advantages in terms of time and effort compared to traditional methods thanks to the ready-made infrastructures (pipelines) they offer (Heymann et al., 2022; Krauß et al., 2020). Owing to these platforms, machine learning models can be put live, their performance can be monitored, and updates and improvements can be provided when necessary (Sculley et al., 2015). Platforms such as Heroku (Hanjura, 2014), MLFlow (MLflow, 2023), KubeFlow (Kubeflow, 2023), Amazon AWS (Amazon Web Services, 2023), Pachyderm (Pachyderm, 2023), and DataRobot (DataRobot, 2023) are examples of MLOps applications.

The aim of this study is to demonstrate the process of implementing a developed machine learning model using a sample data set. In line with this purpose, GitHub, Streamlit, and Heroku platforms are used for the deployment of the model. Heroku web application was preferred in this study because it offers easy implementation among MLOps platforms. In the study, the "Titanic" data set, one of the known data sets, was used and firstly the machine learning model was developed and then the developed model was deployed. Python programming language and related libraries were used to develop the model. All platforms, programs, and libraries used in the study are shown in Table 1.

Table 1

Platform, program, and libraries used in the study

Program/Library	Version	Purpose of use	References
Anaconda Navigator	3.6	Development environment	Anaconda (2023)
Microsoft Excel	2016	Data storage	Microsoft Excel | Microsoft 365 (2021)
Python	3.7.0	Programming language	Van Rossum & Drake (2009)
Numpy	1.14.3	Library for Scientific Computing	Harris et al. (2020)
Pandas	0.23.0	Data analysis and manipulation tool	McKinney (2010)
Scikit-Learn	0.19.1	Data science library	Pedregosa et al. (2011)
GitHub	-	Developer storage service provider	GitHub Inc (2023)
Streamlit	0.77.0	Python framework	Teixeira et al. (2021)

Program/Library	Version	Purpose of use	References
Heroku	-	Cloud-based web platform service	Hanjura (2014)

Development of the Model

Model development processes were carried out in the “Spyder” application on the “Anaconda Navigator” platform (Anaconda, 2023). When the program is installed on the computer, the Python programming language and Scikit-Learn, Numpy, and Pandas libraries are automatically installed (Harris et al., 2020; McKinney, 2010; Python Software Foundation, 2023; Pedregosa et al., 2011). To download the latest version of the Anaconda Navigator to the computer, select the operating system from https://www.anaconda.com/products/distribution#Downloads and click the "download" button (Anaconda, 2023). For the installation file of older versions, go to https://repo.anaconda.com/archive/ and download the desired version, considering the operating system.

Although Anaconda Navigator comes with Python language installed, the program should be installed in the Windows directory in order to run in the Streamlit environment. The latest version of the Python installation file can be downloaded by going to https://www.python.org/downloads/. For previous versions, the page can be scrolled to the bottom and the desired version can be downloaded according to the operating system (Python Software Foundation, 2023). Python version 3.7.0 was used in this study. Installation is completed by running the downloaded installation file and clicking the "next" button on the screen that appears.

Data Set

The "Titanic" data set, one of the well-known data sets, was used in the study. The dataset is available on many websites and can be downloaded from https://www.kaggle.com/datasets/hesh97/titanicdataset-traincsv?select=train.csv. The attributes and descriptions of the data set are as in Table 2.

Table 2

The attributes and descriptions of the data set

No	**Attribute Name**	**Attribute Description**	**Type**
1	PassengerId	Passenger ID	Numerical
2	Survived	Survival status (0-no / 1-yes)	Categorical
3	Pclass	Ticket class (1-2-3)	Categorical
4	Name	Passenger name	Text
5	Sex	Gender (female-male)	Categorical
6	Age	Age of passenger	Numerical
7	SibSp	Number of siblings/ spouses on Titanic	Numerical
8	Parch	Number of children for parents	Numerical
9	Ticket	Ticket number	Text
10	Fare	Ticket cost	Numerical
11	Cabin	Cabin number	Text

No	Attribute Name	Attribute Description	Type
12	Embarked	Boarding port (C-S-Q)	Categorical

There are a total of 12 variables in the data set. The “Survived” variable is the target variable and machine learning classification models will be developed to predict this variable. The other 11 variables are independent (predictor) variables and are used to classify the target variable.

Data understanding

To develop the model, a Python file named “titanic.py” was created in the Spyder program. Libraries required for data analysis should be included in the file.

```
>> import numpy as np
>> import pandas as pd
>> import seaborn as sns
>> import matplotlib.pyplot as plt
>> from sklearn.model_selection import train_test_split
>> from sklearn.metrics import accuracy_score
>> from sklearn.metrics import f1_score
>> from sklearn.metrics import confusion_matrix
>> from sklearn.metrics import classification_report
>> from sklearn.model_selection import GridSearchCV
>> from sklearn.impute import KNNImputer
>> from sklearn.impute import SimpleImputer
>> from sklearn.ensemble import RandomForestClassifier
>> from sklearn.neighbors import KNeighborsClassifier
>> from sklearn.svm import SVC
```

After the necessary libraries are imported, data analysis can begin. First of all, the data set in the “csv” format file is transferred to a variable as a dataframe.

```
>> df=pd.read_csv('train.csv')
```

The appearance of the dataframe is as in Figure 1.

Figure 1

Assigning the data set to the dataframe

In order to display general information about the data set, the following code is applied to obtain an output as in Figure 2.

```
>> print(df.info())
```

Figure 2
General information of data set

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 891 entries, 0 to 890
Data columns (total 12 columns):
 #   Column       Non-Null Count  Dtype
---  ------       --------------  -----
 0   PassengerId  891 non-null    int64
 1   Survived     891 non-null    int64
 2   Pclass       891 non-null    int64
 3   Name         891 non-null    object
 4   Sex          891 non-null    object
 5   Age          714 non-null    float64
 6   SibSp        891 non-null    int64
 7   Parch        891 non-null    int64
 8   Ticket       891 non-null    object
 9   Fare         891 non-null    float64
 10  Cabin        204 non-null    object
 11  Embarked     889 non-null    object
dtypes: float64(2), int64(5), object(5)
memory usage: 83.7+ KB
```

It is seen that the data set consists of 12 columns and 891 rows (samples) and the data type of each variable when Figure 2 is examined. In order to display summary statistical information of the data set, the "describe" function is applied and the output in Figure 3 is obtained.

```
>> print(df.describe())
```

Figure 3
Statistical summary information of the data set

	PassengerId	Survived	Pclass	...	SibSp	Parch	Fare
count	891.000000	891.000000	891.000000	...	891.000000	891.000000	891.000000
mean	446.000000	0.383838	2.308642	...	0.523008	0.381594	32.204208
std	257.353842	0.486592	0.836071	...	1.102743	0.806057	49.693429
min	1.000000	0.000000	1.000000	...	0.000000	0.000000	0.000000
25%	223.500000	0.000000	2.000000	...	0.000000	0.000000	7.910400
50%	446.000000	0.000000	3.000000	...	0.000000	0.000000	14.454200
75%	668.500000	1.000000	3.000000	...	1.000000	0.000000	31.000000
max	891.000000	1.000000	3.000000	...	8.000000	6.000000	512.329200

As summary information; Features such as minimum-maximum values of variables, number of samples, average, and standard deviation value can be displayed.

Data Preprocessing

Missing, inconsistent, and outlier values in the data should be detected and the data set should be made ready for analysis within the scope of the data preprocessing stage (Han et al., 2011; Zhang et al., 2003). First of all, variables that were thought to have no effect on the target variable in the data set were removed. In the Titanic example in this study, the "PassengerId", "Name", "Ticket" and "Cabin" variables

were removed with the help of the "drop" function. Since it is a column-based deletion process, the "axis=1" parameter was used.

```
>> df=df.drop(['PassengerId','Name','Ticket','Cabin'],axis=1)
```

The final version of the data set as a result of removing the specified variables, is as shown in Figure 4.

Figure 4

Image of the dataset after deleting irrelevant variables

df - DataFrame

Index	Survived	Pclass	Sex	Age	SibSp	Parch	Fare	Embarked
0	0	3	male	22	1	0	7.25	S
1	1	1	female	38	1	0	71.2833	C
2	1	3	female	26	0	0	7.925	S
3	1	1	female	35	1	0	53.1	S
4	0	3	male	35	0	0	8.05	S
5	0	3	male	29.6991	0	0	8.4583	Q
6	0	1	male	54	0	0	51.8625	S
7	0	3	male	2	3	1	21.075	S
8	1	3	female	27	0	2	11.1333	S
9	1	2	female	14	1	0	30.0708	C
10	1	3	female	4	1	1	16.7	S

The “isnull” function was used to display missing values in the data set. The following command shows how many missing values there are for all variables (Figure 5).

```
>> print (df.isnull().sum())
```

Figure 5

Missing values in the data set

```
[8 rows x 7 columns]
Survived      0
Pclass        0
Sex           0
Age         177
SibSp         0
Parch         0
Fare          0
Embarked      2
dtype: int64
```

When Figure 5 is examined; After the removal of irrelevant features, it is seen that the number of columns decreased to 8, there are 177 missing values for the "Age" variable and 2 missing values for the

“Embarked” variable. Variables were handled separately to complete missing values. The “Age” variable is numerical, while the “Embarked” variable is categorical. There are different approaches to dealing with missing values (Akpınar, 2014; Hogarth & Furuta, 2012). In this study, the Knn (K-Nearest Neighbor) method was used for missing values in the "Age" column, and the "most frequently repeated value" method was used for missing values in the "Embarked" column. For these operations, “KNNImputer” and “SimpleImputer” functions were used, respectively.

```
>> imp = KNNImputer(n_neighbors=3)
>> df.iloc[:,3:4] = imp.fit_transform(df.iloc[:,3:4])
>> imp2 = SimpleImputer(missing_values = np.nan,strategy = 'most_frequent')
>> df.iloc[:,7:8] = imp2.fit_transform(df.iloc[:,7:8])
```

To explain the above codes, a variable called "imp" is created and the properties of the KNN imputer function (number of neighborhoods = 3, etc.) are assigned to this variable. Since the age variable is at the 3rd index of the dataframe, the KNNImputer function is applied to the age variable by specifying it as [:,3:4] in the "iloc" function. The expression “:” before the comma indicates that it will be applied to all rows of the relevant column. Similarly, since the "Embarked" variable is at the 7th index of the dataframe, the relevant expression was used in the "SimpleImputer" function.

After completing the missing values, categorical values are converted into numerical form so that machine learning algorithms can be applied. Although the "LabelEncoder" function is also used for this process, it was converted manually with the "replace" method in this study.

```
>> df.iloc[:,2]=df.iloc[:,2].replace('female','0')
>> df.iloc[:,2]=df.iloc[:,2].replace('male','1')
```

For the gender variable, “female” values were changed to 0 and “male” values were changed to 1.

```
>> df.iloc[:,7]=df.iloc[:,7].replace('C','0')
>> df.iloc[:,7]=df.iloc[:,7].replace('S','1')
>> df.iloc[:,7]=df.iloc[:,7].replace('Q','2')
```

For the Embarked variable, “C” values were replaced with 0, “S” values to 1, and “Q” values to 2.

After the preprocessing process was completed, the target variable and independent variables in the data set were defined as separate sets. “Y” is the target variable and “X” is the clusters that represent the predictor variables.

```
>> Y=df.iloc[:,0]
>> X=df.drop(['Survived'], axis=1)
```

Since the target variable (Survived) is at index 0 in the dataframe, it can be assigned with the “iloc” function. Since independent variables are variables other than “Survived”, they can be defined as removing the “Survived” column from the dataframe.

In this study, the hold-out method was used as the model validation. The data was divided into two: 80% training set and 20% test set using the “train-test-split” function.

```
>> X_train, X_test, Y_train, Y_test=train_test_split(X,Y, test_size=0.2, random_state=42)
```

Modelling

In the study, three different machine learning models were used as classification methods: Support Vector Machines (SVM) (Cortes & Vapnik, 1995), K-Nearest Neighbor (KNN) (Cover & Hart, 1967), and the Random Forest (RF) algorithm (Breiman, 2001). For parameter optimization, the GridSearchCv method was used. The GridSearchCV method works according to the principle of training the model for all parameter values in the specified range and selecting the best parameter combinations obtained by observing the results (Müller & Guido, 2016; Shuai et al., 2019). The required codes for the KNN model are as follows.

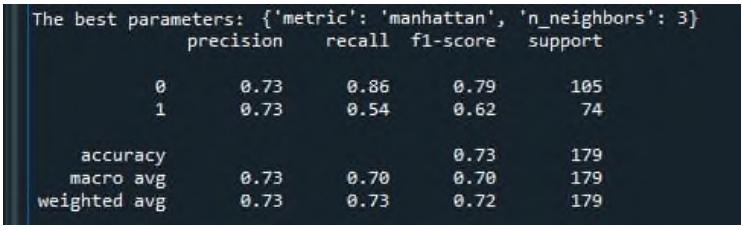
```
>> grid=GridSearchCV(KNeighborsClassifier(),
param_grid={'n_neighbors':[i for i in range(1,10)],
'metric': ['manhattan','euclidean','minkowski']},
scoring='accuracy')
>> grid.fit(X_train,Y_train)
>> print("The best parameters:",grid.best_params_)
>> grid_predictions=grid.predict(X_test)
```

For the KNN algorithm, the number of nearest neighbors parameter (n_neighbors) is tested in the [1-10] range and the distance parameter (metric) is tested with the specified parameter values, and the parameters with the most successful results are saved. Then, the prediction process according to the most successful parameters is carried out with the "predict" function. The following code is applied to display the classification report (Figure 6).

```
>> print(classification_report(Y_test,grid_predictions))
```

Figure 6

KNN classification report



```
The best parameters: {'metric': 'manhattan', 'n_neighbors': 3}
              precision    recall  f1-score   support

           0       0.73      0.86      0.79       105
           1       0.73      0.54      0.62        74

    accuracy                           0.73       179
   macro avg       0.73      0.70      0.70       179
weighted avg       0.73      0.73      0.72       179
```

As seen in Figure 6, optimum parameter values; The number of nearest neighbors parameter was determined as 3, and the distance parameter was determined as 'manhattan'. When the classification report is examined; It is observed that the model reaches an accuracy rate of 73%, and its precision, sensitivity (recall), and F-Score (F1-Score) values are 70%.

The codes of the Support Vector Machines model are as follows.

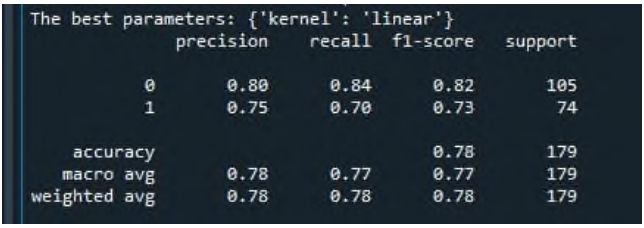
```
>> grid=GridSearchCV(SVC(),
param_grid={'kernel':['linear','rbf']
},
scoring="accuracy")
>> grid.fit(X_train,Y_train)
```

```
>> print("The best parameters:", grid.best_params_)
>> grid_predictions=grid.predict(X_test)
>> print(classification_report(Y_test, grid_predictions))
```

For the SVM model, the kernel parameter is tested with 2 values, "linear" and "radial bases function (rbf)", and the parameter with the highest model success is saved. The Support Vector Machines model classification report is shown in Figure 7.

Figure 7

SVM classification report



```
The best parameters: {'kernel': 'linear'}
              precision    recall  f1-score   support

           0       0.80      0.84      0.82       105
           1       0.75      0.70      0.73        74

    accuracy                           0.78       179
   macro avg       0.78      0.77      0.77       179
weighted avg       0.78      0.78      0.78       179
```

When Figure 7 is examined, it is seen that more successful results were obtained with the "linear" parameter and it was determined as the kernel parameter value. The model reaches a 78% accuracy rate according to the classification report.

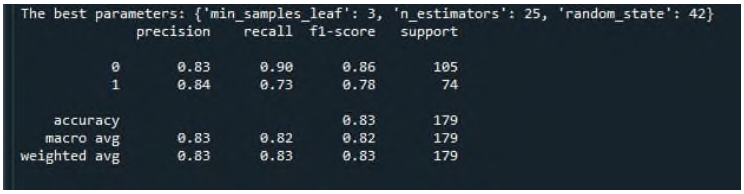
The codes required for the RF model are as follows.

```
>> grid = GridSearchCV(RandomForestClassifier(),
param_grid={'n_estimators':[i for i in range(1,60,4)],
'random_state':[42],
'min_samples_leaf':[i for i in range(1,11)]
},
scoring='accuracy')
>> grid.fit(X_train,Y_train)
>> print("The best parameters:",grid.best_params_)
>> grid_predictions = grid.predict(X_test)
>> print(classification_report(Y_test, grid_predictions))
```

For the Random Forest algorithm, the number of trees parameter (n_estimator) and the minimum number of samples in the leaves of the tree parameter (min_samples_leaf) are tested with values in the specified ranges and the parameters that give the best results are saved. The classification report is shown in Figure 8.

Figure 8

RF classification report



```
The best parameters: {'min_samples_leaf': 3, 'n_estimators': 25, 'random_state': 42}
              precision    recall  f1-score   support

           0       0.83      0.90      0.86       105
           1       0.84      0.73      0.78        74

    accuracy                           0.83       179
   macro avg       0.83      0.82      0.82       179
weighted avg       0.83      0.83      0.83       179
```

As seen in Figure 8, optimum parameter values; It was determined as 25 for the number of trees parameter and 3 for the minimum number of samples parameter. When the classification report is examined; It is observed that the model reaches an accuracy rate of 83%, and precision, sensitivity (recall), and F-score (F1-Score) values support the accuracy rate. When all applied machine learning models are compared, it is seen that the most successful results are obtained with the Random Forest algorithm. Therefore, the Random Forest model will be used in the process of implementation.

In order for the developed machine learning model (Random Forest) to be used in the implementation phase, it should be saved as a separate file. In this context, the “Pickle” library, developed for machine learning model storage, is used (Géron, 2018).

```
>> import pickle
>> file='RandomForestModel.pkl'
>> pickle.dump(grid,open(file,'wb'))
```

The Random Forest model is saved in the current folder of the study with the extension "pkl" when the above codes are applied.

Implementation of the Model

GitHub, Streamlit, and Heroku platforms were used in this study to take the developed model live. Using these platforms, machine learning models can be put live to run on the web. First of all, a user account should be created on Github (github.com) and Heroku (heroku.com) platforms. Streamlit is a framework that provides a ready-made service for machine learning models using the Python infrastructure (Teixeira et al., 2021). In order to run the Streamlit infrastructure on the local server (localhost), the following codes should be applied sequentially in the command prompt (CMD) and the question should be confirmed with the "y" command.

```
>> pip install streamlit
>> pip install scikit-learn
```

Creating the Application File

A new Python file should be created to implement the model after Streamlit is installed. In this study, it was created under the name “titanic_implementation.py”. Necessary libraries have been imported to the created file.

```
>> import streamlit as st
>> import pandas as pd
>> import numpy as np
```

The "Main" function is defined and the title of the web page is specified with the "st.title" command. Optionally, information about the system can be provided in a pop-up box view with the “st.beta_expander” command.

```
>> def main():
st.title("TITANIC DATA SET ML MODEL DEPLOYMENT)
with st.beta_expander ("System Description"):
```

```
st.write("""A Sample System Description """)
```

The following codes have been applied to make the "Main" function work.

```
>> if __name__ == '__main__':
main()
```

Streamlit visual interface needs to be adapted to the developed machine learning model. For example, although the Gender variable is available as (0-1) in the model, it should be chosen as (female-male) in the data entry section of the interface. Therefore, a dictionary was created for categorical variables.

```
>> Sex_dict = {'female':0,'male':1}
>> Embarked_dict = {'C':0,'S':1,'Q':2}
```

A data entry interface has also been created for other variables. The “st.number” function was used for numerical values and the “st.selectbox” function was used for categorical values. The title of the attribute and the value ranges to be entered are specified within the functions. The format for values to be used as decimal in numeric variables is "0.00".

```
>> PClass=st.number_input ("Ticket class",1,3)
>> Sex=st.selectbox("Sex", tuple (Sex_dict.keys()))
>> Age=st.number_input ("Age",0,100)
>> SibSp=st.number_input ("Number of siblings on Titanic", 0,10)
>> Parch=st.number_input ("Number of children",0,10)
>> Fare=st.number_input ("Fare",0.00,500.00)
>> Embarked=st.selectbox ("Boarding port”, tuple (Embarked_dict.keys()))
```

The following codes were applied to take the values of the "Sex" and "Embarked" variables, for which a dictionary was previously created, from the dictionary and post them to the model.

```
>> Sex=Sex_dict.get(Sex)
>> Embarked=Embarked_dict.get(Embarked)
```

The reset process is carried out as follows to send the values entered for the variables in the interface to the relevant fields in the saved model. What is meant by the reset process; It is the transfer of the values received from the interface to a dataframe in accordance with the machine learning model and assigning them to a variable (res).

```
>> res = pd.DataFrame(data =
{'PClass':[PClass], 'Sex':[Sex], 'Age':[Age],
'SibSp':[SibSp], 'Parch':[Parch], 'Fare':[Fare],
'Embarked':[Embarked]
})
```

The “Pickle” library was used to load the previously developed machine learning model. The ml model is transferred to a variable named “model”. The expression “rb” indicates that the model file with the “pkl” extension will be opened in reading mode.

```
>> import pickle
>> with open ('RandomForestModel.pkl', 'rb') as f:
model = pickle.load(f)
```

Then, the "predict" function was used to perform the prediction process with the values entered from the interface. In order to display the prediction value in the Label on the web-form, the value of the prediction variable was converted to "string" data type by using the “str” function.

```
>> prediction = model.predict(res)
>> prediction = str(prediction).strip('[]')
```

A trigger was created for the prediction process from the model by creating a button called Prediction. When the button is pressed, the model's prediction is viewed on the screen.

```
>> if st.button ('Predict'):
>> st.write ("Random Forest Model Prediction: ",prediction)
```

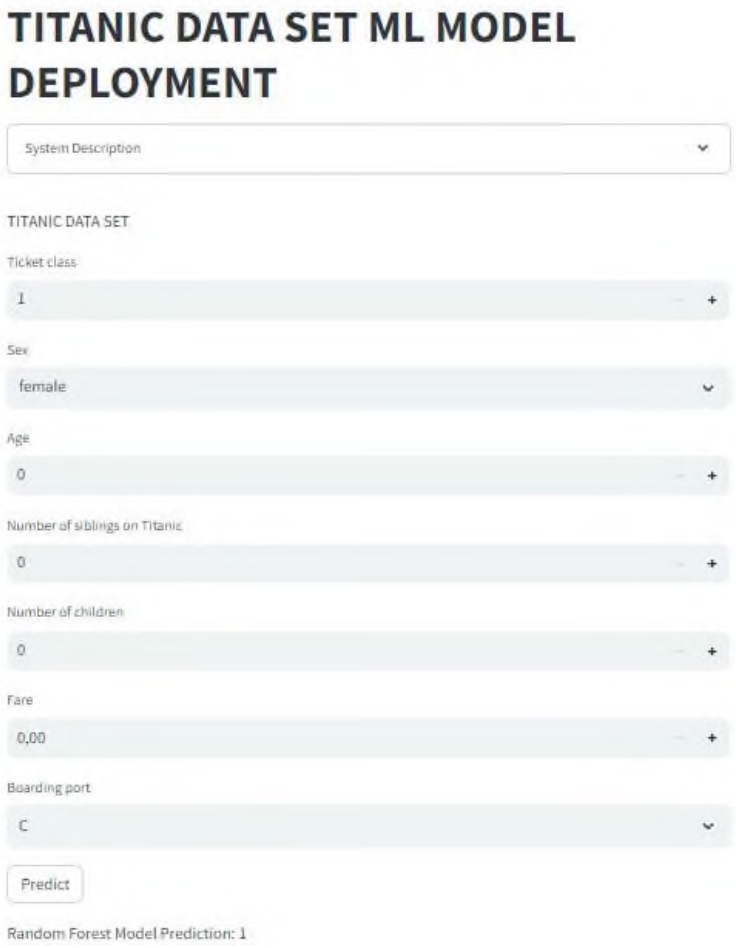
Running the Model on the Local Server

It is significant to run the Python file prepared with the Streamlit framework on the local server (localhost) before deploying it to the web environment in order to correct errors. The following commands should be executed at the command prompt to run the file.

```
>> cd desktop
>> cd ml-model
>> streamlit run titanic_implementation.py
```

Since the files created in this study are located under the "ml-model" directory on the desktop, the relevant directory should be accessed with the "cd" command first. Then, the file is run with the “run” command and displayed on the local server. As a result of these processes, the machine learning model developed runs in the default internet browser on the local server (Figure 9).

Figure 9
Sample image of the model running on the local server

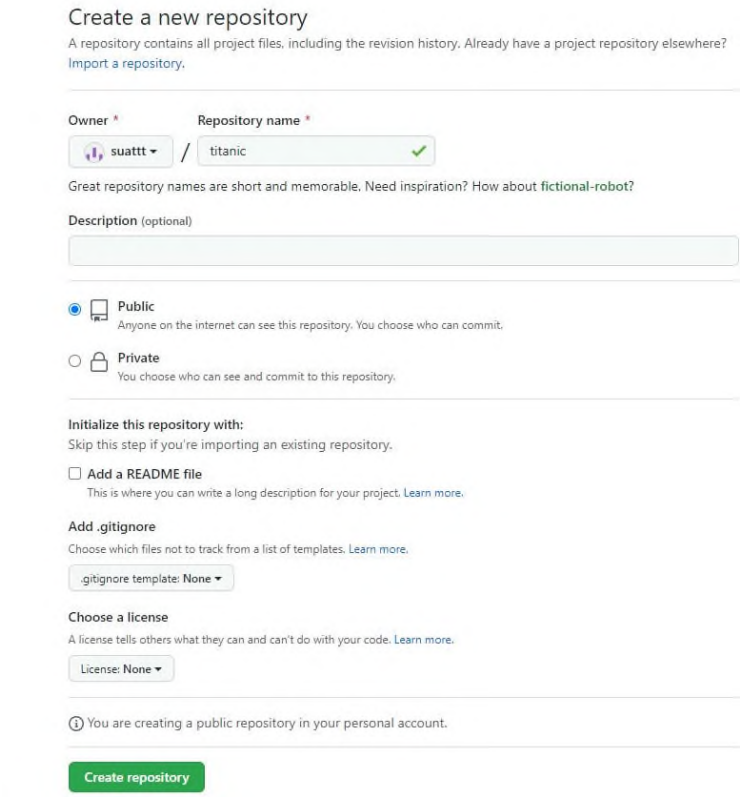


As seen in Figure 9, the model prediction result is viewed on the screen in line with the values entered as an example. In the example here, the survival status of the person whose attributes were entered, was estimated as "1", that is, "yes".

Deploying the Model to the Web Environment

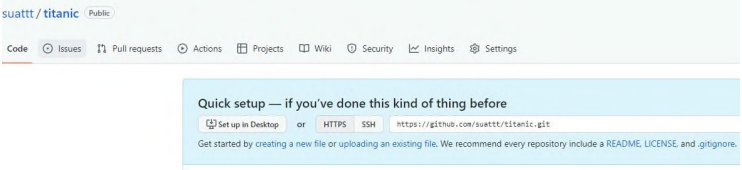
Previously created GitHub and Heroku accounts will be used to transfer the machine learning model to the web environment. After logging into the GitHub platform, a new repository should be created to store the files. To realize this, click on the "new" button in the upper-left section of the home page, write the name of the repository in the window that appears and click on the "Create Repository" button (Figure 10).

Figure 10
Creating the GitHub repo



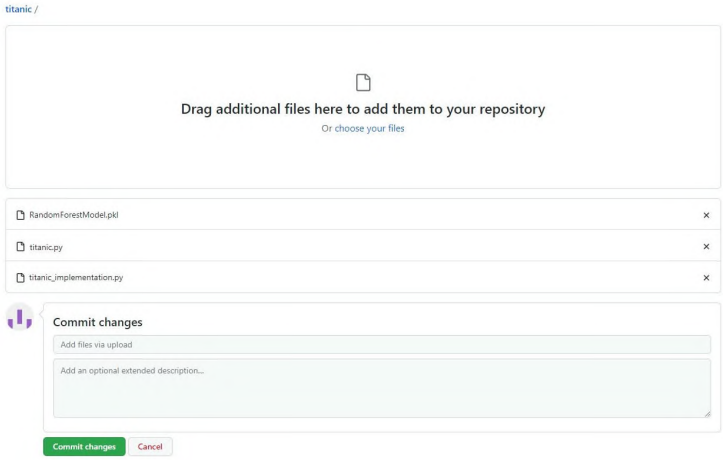
Click the “uploading existing file” option to transfer files to the created repository (Figure 11).

Figure 11
Uploading window for the project files



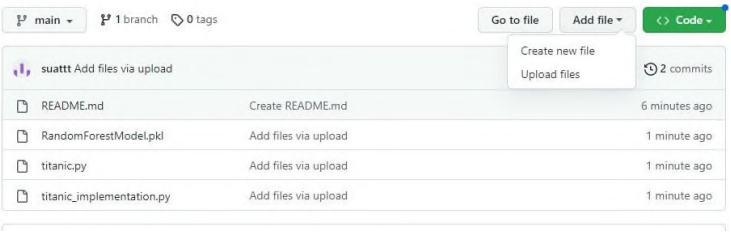
In the window that opens, it's clicked the "choose your files" button and it's selected "titanic.py", "titanic_implementation.py", and the file where the model is saved (RandomForestModel.pkl) on the computer. After the files are uploaded, the changes are saved by clicking the “Commit changes” button (Figure 12).

Figure 12
Uploading project files to the repository



To prepare the necessary settings files for GitHub and Streamlit configuration, click on the "creating a new file" option from the menu shown in Figure 8 or click on the "creating a new file" option under the "add file" menu in the repository section (Figure 13).

Figure 13
Creating new files in the repository

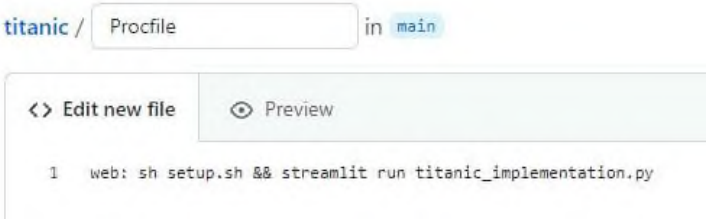


New files are named and the necessary commands are written into the files. What needs to be taken into consideration here is that the file names should be written exactly as the system requires. First, the “README.md” file is created (Figure 14). It is sufficient to add a brief explanation about the developed system in the file. After entering the description, changes are saved with the “Commit new file” command.

Figure 14
Creating the “README.md” file

Then the "Procfile" file should be created. The file name and content should be as shown in Figure 15.

Figure 15
Creating the "Procfile" file

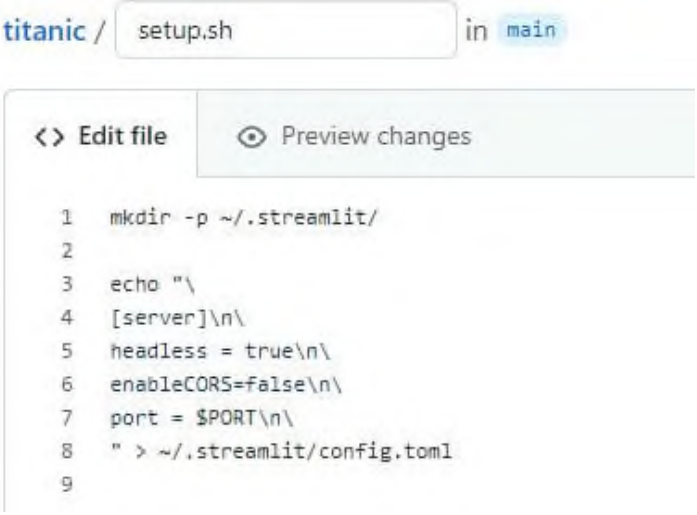


A file named "requirements.txt" should be created for system requirements and the programs and libraries in the study should be specified in the file content along with their versions (Figure 16).

Figure 16
Creating the "requirements.txt" file

The "setup.sh" file should be created to complete the Streamlit configuration (Figure 17).

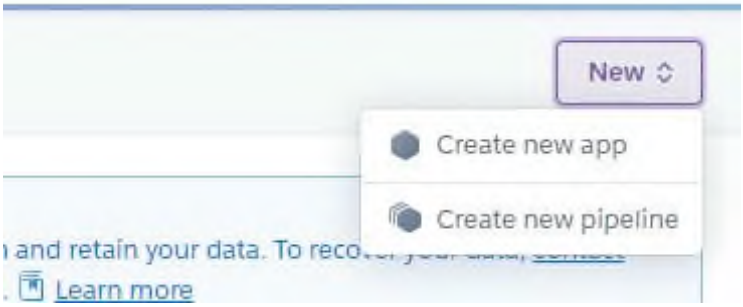
Figure 17
Creating the "setup.sh" file



After the file upload process on the GitHub platform is completed, the Heroku platform is logged in. It's clicked the "Create new app" button under the "new" menu to create an application on Heroku, (Figure 18).

Figure 18

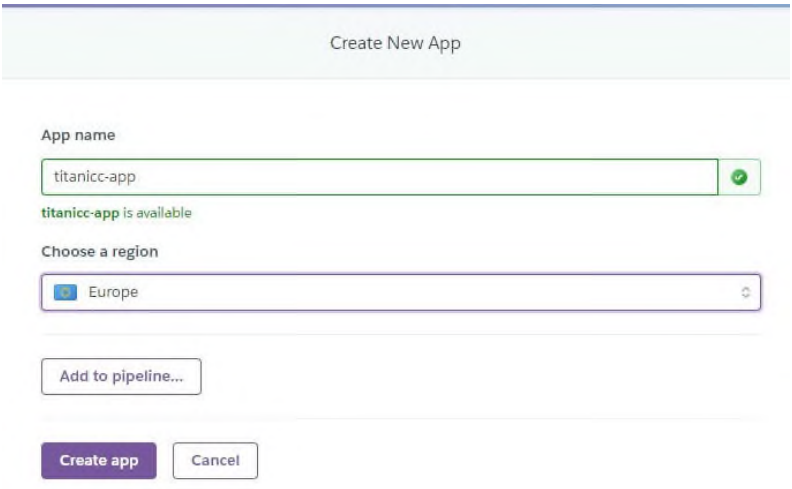
"New application" menu on the Heroku platform



In the menu that will open, the application is given a name that has not been taken before on the platform, the region is selected and the "Create app" button is clicked. In this way, the application is created (Figure 19).

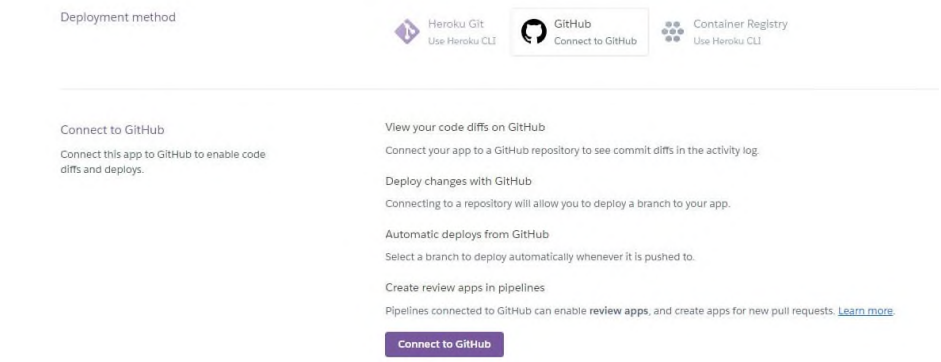
Figure 19

Creating a new application on the Heroku platform



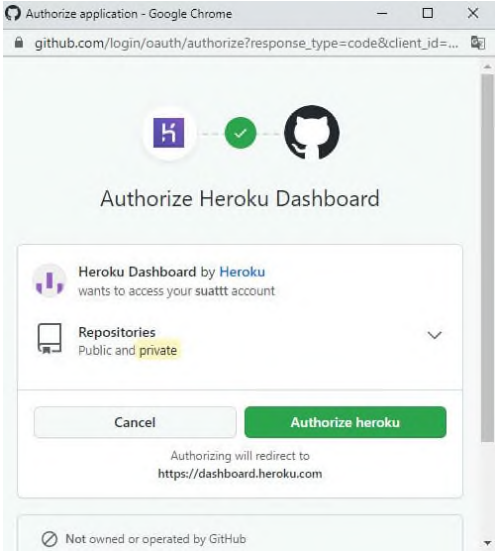
It should be chosen how to add application files from the "deployment" menu under the "deploy" tab on the application screen. The "Connect to GitHub" option should be selected from this screen (Figure 20).

Figure 20
Connecting to GitHub account from Heroku



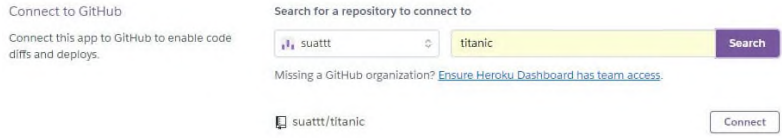
On the screen that will open, the username and password of the GitHub account should be entered, and on the next screen, the "Authorize Heroku" button should be clicked to integrate the Heroku account with the GitHub account (Figure 21). In this way, it will be possible to access the GitHub account from the Heroku account.

Figure 21
Authorizing access to the Heroku account to connect GitHub account



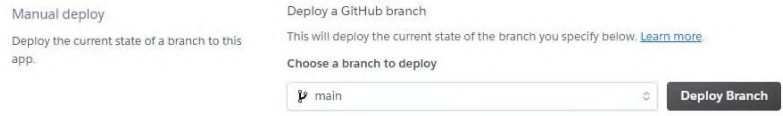
After this process, a connection to the GitHub account is established. To access the repository, it is typed the repository name in the box next to the Gitbhub username in the "Connect to GitHub" section from the "deploy" menu and click the "Search" button. In this study, since the name of the repo is "titanic", it was searched with this name. As a result of the search, the GitHub repository is listed and the “connect” button next to it, is clicked (Figure 22).

Figure 22
Connecting to the repository in the GitHub account



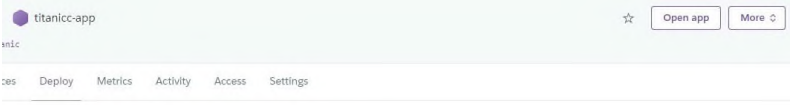
After accessing the repository, the next step is to move the files in the repository to the Heroku platform. To perform this operation, click the "Deploy Branch" button in the "Manual deploy" section and wait for the files and necessary libraries to be loaded (Figure 23).

Figure 23
Transferring files from GitHub to the Heroku



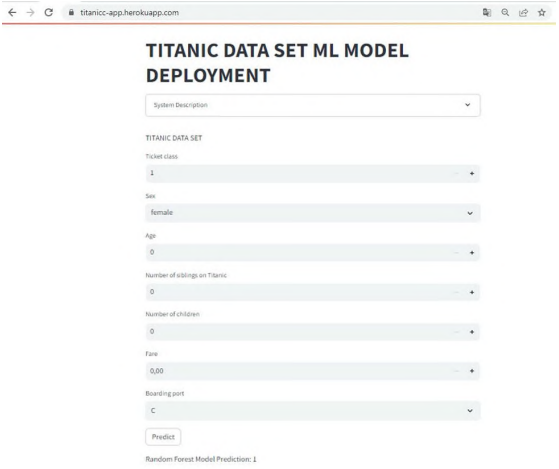
When the “the installation is successfully completed” message is received, the process of converting the machine learning model into a working web application is ended. The view of the application on the web platform is accessed by clicking the "Open app" button on the right side of the application section, (Figure 24).

Figure 24
Running the developed application



The application running on the web environment is shown in Figure 25.

Figure 25
View of the model on the web



The model can be accessed from the web address automatically defined by Heroku when the process is completed. The model developed in this study can be accessed at https://titanicc-app.herokuapp.com/.

Conclusion

It is very valuable to be able to use machine learning as a tool in the process of transforming data into information that will add value to people. In this study, the implementation phase of the machine learning process, in other words, the deployment of the developed models, is demonstrated, and as a result, a sample tool is presented. This study, which aims to help you use this tool by applying it step by step on a publicly available data set, also has its limitations. Within the current circumstances, it was preferred to use the most widely used language, libraries, platforms, and publicly available data sets. Due to the limited resources in the literature regarding the implementation phase of the machine learning process, this study is considered to contribute to the literature and serve as a guide for future studies. In the future, it is recommended to apply the foundation gained here to different data sets and reinforce it with different platforms, packages and languages. Developing similar tools using different programming languages and libraries will be beneficial in terms of flexibility, efficiency, and compatibility. Additionally, working with specialized datasets will enable addressing more unique and specific problems.

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Chapter 14

Missing Data Completion: An Example of Microarray Dataset

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Abstract

In today's information age, data is analyzed by various methods in the process of obtaining information that is more valuable than data. During the pre-processing phase of data analysis, missing data in the data sets can be completed by applying data completion methods. It is especially important to complete missing data so that some machine learning algorithms can work smoothly. Regarding completing missing data; There are many different methods such as filling with the average, filling with the median, and filling with the KNN algorithm. The appropriate method is determined according to the data set and missing data is completed.

In this study, the missing data completion problem is exemplified with a publicly shared microarray dataset. Microarray datasets consist of numerical data representing gene expression level. A data set containing missing values was created by deleting the existing data in the data set coded GDS737 in the NCBI GEO data repository. Mean and median filling, k-neighborhood algorithm, multivariate regression, and deep learning machine learning algorithms were applied to complete missing data. To determine the performance of these algorithms, their predictive power on deleted data was compared. As a result, it was determined that multivariate regression and deep learning algorithms best predicted the missing data.

Keywords Missing data completion · microarray · multivariate regression · deep learning · knn

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Introduction

Gene expression data generated with the help of microarray technology is often analyzed for disease diagnosis and treatment. However, this data may be subject to missing values, which may lead to erroneous findings (Farswan et al., 2020). When missing data is encountered, it is necessary to carry out a preprocessing study to complete the missing data appropriately. If the dataset containing missing data is large enough, deleting records containing missing data may not cause a problem. However, if the dataset is not large enough, deleting observations will further reduce the data; Thus, it will weaken the power of the analysis to be made.

Many studies have been conducted to ensure that missing data encountered in microarrays are completed through prediction. In a study by Chiu et al. (2013), an evaluation of the performance of nine missing data completion algorithms was presented on microarray datasets of various types and sizes. Two completion approaches were tried in this work: a) local completion algorithms and b) global completion algorithms. To complete missing values in local complementation methods, the group of genes most related to the target gene was determined by calculating Pearson correlations or covariances. As local completion algorithms, k nearest neighbors (KNN), iterative k-neighbors (IKNN), sequential k-neighbors (SKNN), least squares (LS), adaptive least squares (LSA), local least squares (LLS).), iterative least squares (ILLS) and sequential least squares (SLLS), as well as these algorithms, singular value decomposition (SVDimpute) and Bayesian principal components analysis (BPCA) were used among global imputation algorithms. To reveal the performance differences between the methods, NRMSE and CPP and BLCI metrics were preferred in the time series. The result of this study shows that ILLS and SLLS have better performance for time series data. For non-time series data, when performance was evaluated using NRMSE, it was concluded that LS was the best algorithm. In another study (Dubey & Rasool, 2021), local completion method was applied to microarray gene expression data. To reduce the computational cost, some techniques have been applied to make the matrix sparse using k nearest neighbors. Research results on gene data revealed that the proposed method outperforms other existing assignment methods. In a study by Troyanskaya et al. (2001), least squares and cluster structure-based completion methods were proposed to estimate missing values in microarray expression data. The proposed least squares-based method is based on considering a target gene with missing values as a linear combination of similar genes. Pearson correlation coefficient was used to select the genes to be analyzed. We can mention another study that used least squares-based complementation methods to estimate missing values in gene expression data. The local least squares imputation method, also proposed in this study, is based on a target gene with missing values as a linear representation of similar genes (Kim et al., 2005).

Today, deep learning techniques are used extensively in classification processes and datasets containing continuous data in almost every field. In parallel with this trend, it has started to be used in missing data completion operations. In their study, Lin et al. (2022) used machine learning algorithms to complete missing data and compared the performance of missing value imputation models using deep neural networks for continuous data. Deep learning and deep belief networks (DBN) are built based on optimal parameters set in some pre-training tests. In missing data completion based on these two algorithms, deep learning and deep belief networks were found to significantly outperform baseline completion models, including averaging, KNN, CART, and SVM methods on fourteen datasets with 10% to 50% missing rates.

Missing Data Completion Methods

There are many methods in the literature to estimate missing data. Missing data completion methods (mean and median, KNN, multivariate regression and deep learning machine learning algorithms) applied within the scope of this study are explained in this section.

Fill in missing data with mean and median

If it is necessary to complete the data set by estimating missing data, some methods can be used for numerical data types. For this purpose, in order to estimate the missing data of an attribute, the average or median values of the attribute values in question can be calculated in its simplest form. If an attribute contains missing values, the missing values are subtracted from the attribute values and the average of the remaining values is calculated according to relation (1).

$$\overline{x} = \frac{1}{n}\sum_{i} x_i \qquad (1)$$

$$x_i : \text{Observation values}, i = 1, 2, ..., n$$

The resulting average value is assigned to replace missing data. Another method of missing data completion is through median calculation. Since mean or median values are calculated only on the relevant attribute, the same value estimate is obtained instead of all missing values on that attribute. After sorting the observations excluding attribute values containing missing data, the middle element is obtained as the median. By assigning this value to the missing data, missing data is completed.

Completing Missing Data with K Nearest Neighbors Algorithm

This method is based on calculating the distance between observations. Euclidean relation can be used in calculations between two observations. The distance between two given observations, p and q, is calculated in the n-dimensional Euclidean space according to the following relation (2):

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} \qquad (2)$$

If generalized for n-dimensional Euclidean space, the above relation can be expressed as shown below (3).

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + ... + (p_1 - q_n)^2} \qquad (3)$$

Below is the weighted "distance relation" in calculating new values for observation values containing missing values using the k-nearest neighbors algorithm (KNN) used:

$$\text{weight} = \frac{\text{Total number of observations}}{\text{Number of obs ervations with out missing values}} \qquad (4)$$

d_i=Weighted distances between observations

$$d_i = \sqrt{\text{weight*squared distances for current coordinates}} \qquad (5)$$

These calculations are made for k observations. It is selected as the new value of the observation value containing missing values $\min(d_i)$.

Completing Missing Data with Multiple Regression Analysis

If variable Y takes various values for each of the values that an independent variable X can take, it is said that there is a relationship between these two variables. It is relevant for various fields to investigate the relationship between two variables. Price and demand for a good in economics, income and tax in finance, production and profit in business, age and recovery from disease in medicine, etc.

With regression analysis, it will be possible to predict the dependent variable Y, that is, the demand for the product, with the help of the independent variable X, for example, advertising expenditures. This Y value can be estimated by a "least squares line" fitting the observation values. Since Y values are predicted by X, this line is called the "regression line of Y with respect to X ". In linear regression, there can be more than one independent variable. In this case, "multiple linear regression" occurs. In this type of model expression, variables can be included in the matrix structure as shown below:

$$\begin{gathered} Y = X\beta + \varepsilon Y : \text{Independent variable} \\ X : \text{Dependent variables} \\ \beta : \text{Regression coefficients} \\ \varepsilon : \text{Error term} \end{gathered} \tag{6}$$

The resulting multiple regression model is used in predictions. It is in the form of a prediction model $\hat{Y} = X\hat{\beta}$. In this prediction model, $\hat{\beta}$the coefficients are obtained as shown below. It is required:

$$\hat{\beta} = [X^T X]^{-1} X^T Y \tag{7}$$

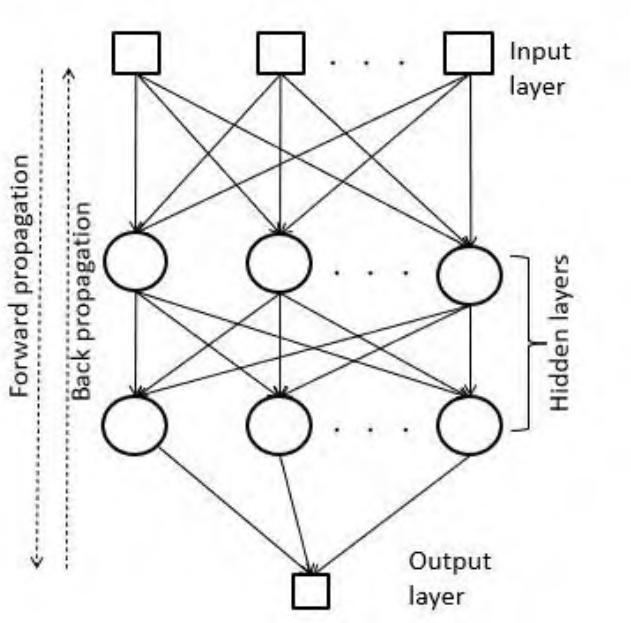
In order for this method to be used in the data completion process, first the observations with missing data in the relevant data set and the attributes to which these observations belong are selected. Observations with missing data are moved to another dataset. This new dataset is treated as test data. In model creation, an attribute with missing data is determined as the dependent variable, and the other attributes are determined as the independent variables. Missing data completion values are obtained by applying test data to the trained regression model.

Completing Missing Data with Deep Learning Regression

Deep learning networks are a structure consisting of many hidden layers along with input and output layers, as seen in Figure 1. Starting from the input layer, observation values move between layers and neurons and change to obtain output values. The purpose of this change is to ensure that the estimates produced for the output values are as close as possible to the actual output values.

Each hidden layer of the network consists of neurons, and these neurons communicate with each other and with the input and output layers. Deep learning networks are created from as many hidden layers and neurons as needed (Chollet, 2019). The data inputs layer consists of the attribute values of the dataset. Relevant data sets are read into the network in the form of rows through this layer. The output layer represents an attribute of the same data set that is not included in the input layer. If the established model is for classification purposes, each output value contains a class. If the outputs are continuous, this time only one output is mentioned. In the regression model, the output value is evaluated as a numerical value (Özkan, 2021). Hidden layers process the data coming from the input layer and transfer it to the next hidden layer elements. In artificial neural networks, each connection has a weight. This is the basis of artificial neural networks w_k creates weights. These weights determine the relationships between the inputs and outputs of the network. The inputs and outputs of a nerve are calculated sequentially. This calculation process is the “forward propagation” phase. The net input value calculated for each nerve is transformed with an activation function to obtain the output of the nerve (Öztemel, 2016).

Figure 1
Deep learning model (Özkan & Erol, 2018)



The difference between the values obtained in the output layer of the established deep neural network and the actual outputs is calculated. Thus, the error obtained as a result of forward propagation, or in other words its cost, is calculated. In the back propagation process, the error obtained as a result of forward propagation is distributed to all weights in the network. As a result of these operations, it is tried to make the predicted value closer to the real value and thus reduce the error. For this every w_k In order to determine the effect of the change in the weight on the total error, the derivatives are calculated according to the weight in question and the learning rate is calculated. η is multiplied by and thus the amount of change in the weights is calculated. The weight is updated by subtracting the resulting value from the previous weight in question (8).

$$w_k^{yeni} \leftarrow w_k - \eta \frac{\partial E_{toplam}}{\partial w_k} \tag{8}$$

The completion method for datasets containing missing data is the same as the process followed for the multivariate regression method. First, the observations with missing data in the relevant dataset and the attributes to which these observations belong are selected and moved to a new dataset to be used as test data. The new dataset is used as test data, and the remaining dataset is used to train the prediction model. The prediction process is carried out by applying test data to the trained regression model, thus completing the missing data completion process.

Material and Methods

Python programming language (Rossum & Drake, 1995), Tensorflow (Abadi et Al., 2015), Keras (Chollet et al., 2015) and Scikit-learn (Pedregosa et al., 2011) were used in the modeling and prediction stages to complete missing values in the microarray dataset, packages were used.

Microarray Dataset

Within the scope of this study, the dataset coded GDS737 in the NCBI GEO data platform was used. This dataset was organized by Spira et al. (2004) to provide information about the pathogenesis of chronic obstructive pulmonary disease (COPD). The dataset includes 30 observations and 22282 attributes (genes). Regarding the lung tissue of smokers with severe emphysema, the GDS737 coded dataset in the NCBI GEO data platform (Edgar et al, 2002) was considered and missing data completion methods were applied on this dataset (Spira et al., 2004).

Data Preprocessing

The aim of this study is to demonstrate the most successful method by applying different missing data completion methods on the GDS737 coded data set. However, in order to find the performance of the method at the end of the data completion process, the true value of an observation value detected as missing data in the dataset in question must be known. For this reason, data in different locations in the dataset were deleted in a controlled manner. In this context, on the dataset coded GDS737, GSM28374, GSM28380, GSM28386 and GSM28360 observations belonging to the gene named "GUCA1A" and GSM28358, GSM28369, GSM28375 and GSM28365 observations belonging to the gene named "THRA" were deleted and a new dataset containing missing data was created. The values before deletion are in Table 1. At the end of the deletion process, missing data completion methods were applied to this data set and the obtained results were compared with known real values.

Completing Missing Data

Two traditional statistical methods based on mean and median calculation and 3 machine learning algorithms (KNN, multivariate regression, and deep learning) were applied to complete the missing data. There are usually no assumptions to check when implementing machine learning regression algorithms. The algorithm can be applied directly to the data under almost any conditions. After applying these methods, completion values that could replace missing data were obtained with the models obtained. Their performance was calculated by looking at the mean square error (MSE) value between these values. The MSE performance measure y_i is calculated with the help of the following equation to show the actual values, $\hat{y}_i$ predicted values and number of elements (9).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{9}$$

Complementing with mean and median

In the GDS737 coded data set containing missing data, the average method and median method were applied for the four observation values of the genes named "GUCA1A" and "THRA" as specified in Section 2.1.

K nearest neighbors algorithm

Another method that can be used to complete missing data is the k nearest neighbor algorithm. This algorithm was used to fill in missing data identified for the two genes of the microarray discussed above. In order to apply this algorithm, $k$the number of neighbors must first be determined. This parameter is the number of genes closest to the missing data. It was determined in the required parameter $k = 2$ format. The weighted distances of the observation with missing data to other observations were calculated according to equation (5). When the observations were sorted according to the distances

determined in this way, the value contained in the closest observation was assigned as the missing value. Predictions were obtained as a result of running the model.

Completion with regression method

In the dataset containing missing data, multivariate regression method was applied for four observations belonging to the genes named “GUCA1A” and “THRA”. In order to apply this method, observations with missing data in the dataset were removed from the dataset, the remaining ones were obtained as a training dataset, and a separate test dataset was obtained from the removed ones. A multiple regression model was obtained by considering the 30 variables in the training data set. The performance of the model was calculated using the test data. Each of the microarray arrays contains numerical gene expressions. The same algorithms can be applied to any application involving such data.

Complementing with deep learning

In order to complete the completion process with deep learning, the relevant data set was divided into two parts: training and testing, as in the multiple regression method. Observations with missing data were selected as test data. A deep learning model was created on the remaining variables. The attributes with missing data were selected as dependent variables, and the remaining first 50 variables were selected as independent variables. In the deep learning model, there were 2 hidden layers apart from the input and output layers, and 100 neurons were defined in each of the model hidden layers. “relu” was preferred as the activation function. MSE was chosen as the error function and the "adam" method was chosen as the optimizer. Predictions were improved by applying test data to the prediction model obtained as a result of training the deep learning model.

Results

In order to complete the missing data, the data set created by deleting the GSM28374, GSM28380, GSM28386 and GSM28360 observation values of the gene named "GUCA1A" and the GSM28358, GSM28369, GSM28375 and GSM28365 observation values of the gene named "THRA" on the GDS737 coded data set; mean and median filling, KNN, multivariate regression and deep learning machine learning algorithms have been applied. The prediction and mean square error (MSE) values obtained as a result of this application are presented in Table 1.

Table 1

Predictions of methods to complete missing data

Genes	Observations	real value	Predicted by average method	Predicted by median method	Predicted by KNN method	Predicted by multiple regression	Predicted by deep learning
GUCA1A	GSM28374	37.8	26.67	23.8	23.9	37.8	37.8
	GSM28380	2.4	26.67	23.8	13.6	2.4	2.4
	GSM28386	16.1	26.67	23.8	13,17	16.1	16.1
	GSM28360	4.5	26.67	23.8	28.02	4.5	4.5
THRA	GSM28358	105.7	89.0	92.7	98.99	105.7	105.7
	GSM28369	62.8	89.0	92.7	69.6	62.8	62.8
	GSM28375	71.7	89.0	92.7	89.74	71.7	71.7

Genes	Observations	real value	Predicted by average method	Predicted by median method	Predicted by KNN method	Predicted by multiple regression	Predicted by deep learning
	GSM28365	88.3	89.0	92.7	81.52	88.3	88.3
MSE			326, 1(10)	329, 8(11)	167.89	0	0

As seen in Table 1, the predictions obtained by the mean method, median method and KNN method in the microarray data set did not converge to with the real values. Looking at the MSE values, it is seen that the KNN method gives better results among these three methods. As shown in Table 1, the actual values and the predicted values overlapped in multiple regression and deep learning methods.

Conclusion

Naturally, high performance in terms of accuracy is expected in the analysis of health-related data sets. The data preprocessing phase may affect this performance. For this reason, it is necessary to introduce methods that can best complete missing data. Nowadays, new knowledge discovery studies are commonly carried out by reanalyzing data from publicly shared microarray data sets related to health (Bawa et al., 2021; Erol et al., 2023). In this study, a microarray If data loss is encountered in the dataset, how the missing data can be estimated by using some methods to eliminate this situation is discussed. If missing data is not completed, problems may be encountered in analyzes based on the data in question. Desired results may not be achieved, especially in machine learning and some statistical analyses.

This study focused on how to fill in missing values in microarray datasets containing missing data. As a result of these processes, it was necessary to compare the performance of the methods, so the missing data set was obtained in a controlled manner. In the GDS737 coded microarray dataset, 8 missing values for the genes named "GUCA1A" and "THRA" were created in a controlled manner. In the resulting dataset containing missing data, mean, median, k nearest neighbors, multiple regression and deep learning methods were applied to complete the missing values. The performance of each model was obtained as shown in Table 1. When these results are evaluated, it is understood that the mean and median methods are very weak in terms of MSE value in predicting missing values of the microarray dataset. It is seen that the performance of the K neighbor algorithm is low according to the prediction results. It has been observed that the performance of the remaining multiple regression and deep learning methods is much higher than the others. Lin et al. (2022) also share that deep learning algorithms provide similar results in their studies. Our findings suggest that similar results may be valid for microarray data sets.

Microarray missing data completion studies in the literature (Chiu et al., 2013; Dubey & Rasool, 2021; Kim et al., 2005;Troyanskaya et al., 2001), machine learning algorithms were applied differently in this study. As a result, it is recommended to apply multiple regression or deep learning algorithms in the missing data completion stage in microarray datasets. The analysis is limited to a single microarray dataset. It is recommended to repeat the research with a wider range of microarray datasets in the future. Evaluating the missing data completion methods on microarray datasets with varying characteristics would provide a more comprehensive understanding of their strengths and weaknesses. Additionally, it may be useful to apply the missing data completion methods to microarray datasets where the number of observations is relatively small. Exploring the performance of these techniques on datasets with limited observations could provide insights into their robustness and suitability for scenarios where data availability is a constraint.

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Chapter 15

Real-Time Data Collection and Analysis of User Experience in Video Games: A System Proposal

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Abstract

This research proposes an integrated, data-driven approach to enhancing user experience in video games by combining real-time analytics, eye-tracking, facial expression recognition, and process mining. Traditional evaluation methods—such as surveys, interviews, and basic gameplay statistics—often fail to capture the immediacy and nuance of player emotions, resulting in incomplete or biased insights. To address these limitations, the proposed system collects and analyzes synchronized data from both in-game events and players' real-time emotional states. Eye-tracking data captures user attention and cognitive load, while facial recognition, supported by convolutional neural networks (CNN) trained on public datasets such as FER-2013 and AffectNet, enables the classification of emotional responses during gameplay. Simultaneously, process mining techniques are applied to event logs to uncover behavioral patterns, gameplay bottlenecks, and user flow disruptions. This multi-modal framework not only allows for deeper understanding of player behavior and emotional engagement but also offers a scalable and developer-friendly solution compatible with major game engines such as Unity, Unreal Engine, and Godot. Ultimately, the system aims to support the creation of adaptive, personalized, and immersive gaming experiences—aligning player expectations with game design in real time.

Keywords Gaming experience · deep learning · process mining · emotion recognition · game design

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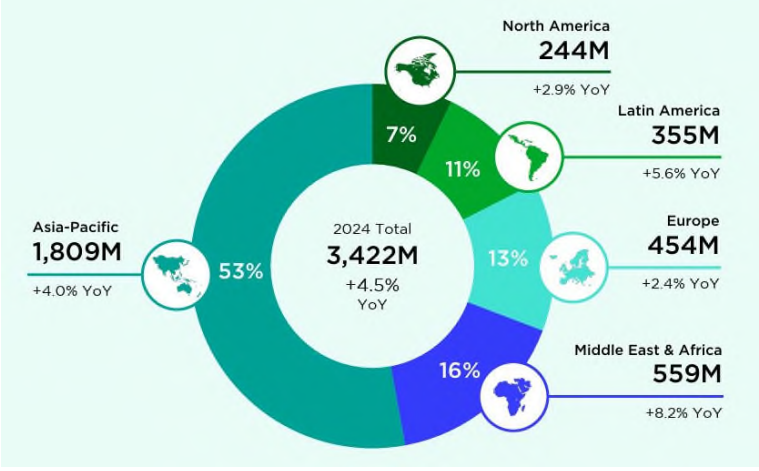
> "You can deny, if you like, nearly all abstractions: justice, beauty, truth, goodness, mind, God. You can deny seriousness, but not play."
>
> — Johan Huizinga, Homo Ludens: A Study of the Play-Element in Culture

Introduction

Video gaming has become a deeply integrated and enduring aspect of modern life. According to recent data, the global number of video game players reached 3.42 billion in 2024, marking a 4.5% increase from the previous year. The Asia-Pacific region continues to lead globally, comprising 53% of all players, which corresponds to approximately 1.809 billion individuals. The Middle East and Africa represent the fastest-growing region, with an annual growth rate of 8.2% and a total player base of 559 million. Although North America and Europe account for smaller shares—7% and 13%, respectively—they remain critical markets in terms of revenue and innovation. Latin America also shows consistent expansion, recording a 5.6% growth rate and reaching 355 million players (see Figure 1). Furthermore, the global video game market is expected to grow at a compound annual growth rate (CAGR) of 3.7% between 2024 and 2027, reaching an estimated value of USD 198.4 billion by 2027 (Newzoo, 2024). On the other hand, the gaming industry has expanded its market size over the past 25 years through advancements in hardware, software, and network connection speeds. Developments in hardware have generally focused on increasing capacity and performance, while prices have decreased due to mass production and gains in efficiency (Thompson & Spanuth, 2021).

Figure 1

Number of video gamers worldwide in 2024, by region.



Source: Newzoo, 2024:18

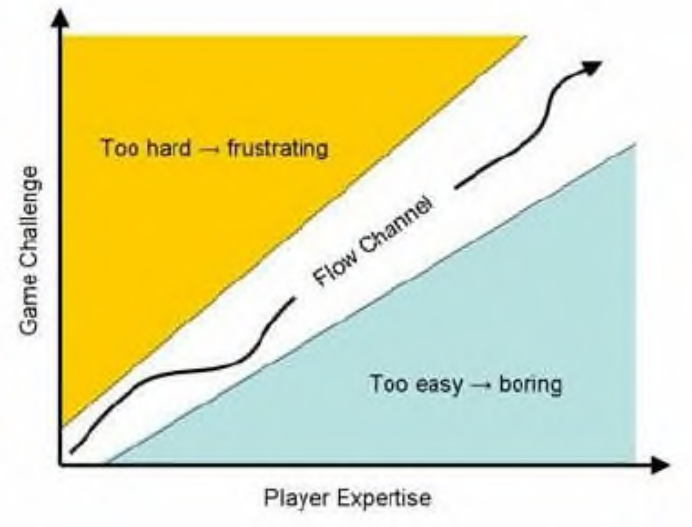
In the domain of software, advancements have progressed along two distinct trajectories, largely driven by increased hardware capacity and reduced costs. First, the development of more sophisticated software solutions—capable of leveraging enhanced hardware resources—has become feasible (Lowood, 2014). Second, there has been a rise in programming languages and software development tools designed to enhance developer productivity (Srinath, 2017). In parallel, network technologies have evolved to offer higher data transfer speeds, greater mobility, and more affordable access, thereby supporting the widespread adoption of digital platforms (Afolabi et al., 2018).

These technological advancements have facilitated the development of more sophisticated games while simultaneously raising player expectations. For game development companies, increasing market

share now depends on attracting the maximum number of players and sustaining their engagement by conceptualizing player interaction through the lens of a 'flow channel.' Achieving this requires a deep understanding of player behavior, needs, and expectations, with a particular emphasis on personalized gameplay experiences. In practice, this often involves designing game levels that align with player capabilities through iterative processes such as playtesting. For example, while in-game data may reveal the frequency of player deaths across various maps and difficulty levels, such quantitative measures alone fail to capture the player's subjective experience. Understanding this affective dimension is central to maintaining players within the flow channel—a state wherein a balance is achieved between player skill and in-game challenge, thereby avoiding frustration or boredom (see Figure 2).

To meet evolving expectations and enhance revenue streams, many game development companies have shifted from a product-oriented logic to a service-dominant logic. In this context, technologies such as LiveOps have emerged, enabling developers to deliver continuous, player-informed updates and content modifications (Dubois & Weststar, 2021). In theory, these tools even allow for the delivery of player-specific content, thereby further personalizing and optimizing the gaming experience

Figure 2
Flow channel



Source: Kraaijenbrink et al., 2009: 302

Delivering player-specific content is only feasible when player expectations are adequately understood—an understanding that necessitates the collection and analysis of empirical data. To this end, user analytics software embedded within games is commonly employed (Plaza, 2011). In addition, traditional methods such as surveys and interviews have been used for decades to capture player feedback. Recent years have witnessed increasing efforts to develop standardized measurement tools and scales to assess player experience (Berkman et al., 2022; Keebler et al., 2020; Mandasari & Pudjoatmodjo, 2019; Phan et al., 2016). However, a review of the relevant literature reveals significant challenges in generalizing findings due to the use of divergent scales across different game genres and platforms. This lack of standardization complicates the comparison of player experiences, even among similar types of games (Aker et al., 2020a; 2020b; Denisova et al., 2016; Li et al., 2021; Melhart et al., 2021; Nordin et al., 2014; Power et al., 2017; Zheng & Lee, 2020; Zulfa et al., 2020).

To sum up, data analytics software, which is the first of these two forms of data collection, provides information about the events during the gameplay but does not provide any data about the user experience. On the other hand, surveys and interviews simply measure user experience but it lacks data about the events that happened during the gameplay. It should also be noted that various concerns about the effectiveness of measuring user experience in games with traditional methods (Schell, 2008).

An alternative line of research has employed heuristic approaches to assess gaming experiences; however, these studies have often been limited in scope, focusing on narrow samples and specific game titles. A more recent study by Inal and Wake (2023) took a different approach by considering players' prior gaming experiences as a variable to explore how these past experiences influence current engagement with a mobile video game.

In recent years, the integration of advanced technologies into video games has led to substantial transformations in the evaluation and optimization of user experience. The field of human-computer interaction (HCI) has increasingly focused on immersive gaming environments, leveraging tools such as eye-tracking, facial recognition, and user analytics to enable more personalized and adaptive gameplay. Although traditional methods—such as surveys and interviews—have long served as foundational approaches in user experience research, the emergence of real-time, data-driven techniques offers the potential for more nuanced and accurate insights into player behavior and emotional responses.

In response to contemporary technological advancements in the video gaming industry and the evolving expectations of users, this paper proposes a novel approach that integrates in-game event data with user experience metrics by combining user analytics software and eye-tracking technology. Specifically, gameplay data will be captured through embedded instrumentation within the game environment, enabling the monitoring of player behavior. This behavioral data will be complemented by emotion recognition analysis derived from facial expressions, processed using convolutional neural networks (CNNs) trained on publicly available datasets such as FER-2013 and AffectNet. The CNN models will be employed to extract features from facial imagery and classify emotional states, with performance optimized through hyperparameter tuning and cross-validation. Evaluation metrics including accuracy and F1-score will be used to assess model performance.

To further analyze player interaction, the study incorporates process mining techniques to derive process models from gameplay event logs, thereby uncovering behavioral patterns. The overarching aim of this methodology is to facilitate the dynamic adaptation of gameplay in response to player emotions. The proposed system is designed to be compatible with widely used game engines such as Unity and Unreal, thereby supporting broader applicability for game developers.

The proposed approach offers a form of user-centered design by mining gameplay processes and dynamically adapting the gaming experience based on user expectations. The following section outlines the key components of the proposed system and presents a detailed roadmap for its development. As the primary objective of this study is to introduce a conceptual framework, the concluding section will focus on the anticipated outcomes and discuss the potential implications of its practical application for the video game industry

Video Game Analytics and User Experience Measurement

Traditional methods of assessing user experience in games—such as surveys, interviews, and gameplay statistics—remain valuable but are constrained by limitations including recall bias and an inability to capture real-time emotional responses (Schoenau-Fog, 2011). As a result, real-time analytics incorporating technologies such as eye-tracking and facial recognition have gained increasing attention as more effective means of capturing the nuances of player experience. For example, Shaker et al. (2016) highlight the significance of player modeling in game design, noting that real-time analytics

can offer insights into player skill levels, preferences, and engagement. When integrated with adaptive systems, such insights have the potential to enhance gameplay experiences and improve overall player satisfaction.

The use of user analytics software in the gaming industry has advanced considerably in recent years. As noted by Bakkes et al. (2012), such tools enable the real-time customization of gameplay experiences by leveraging data collected during play sessions. These analytics systems are particularly valuable for identifying gameplay bottlenecks, uncovering behavioral patterns, and generating predictive insights related to player retention and satisfaction. When integrated with emotional data—such as that obtained through eye-tracking and facial expression recognition—user analytics can offer a more comprehensive understanding of players' emotional responses to in-game content, thereby enhancing the potential for adaptive and personalized game design.

Advances in Eye-Tracking and Emotion Recognition Technologies

Eye-tracking technology, which records where and for how long a user directs their gaze, has emerged as a valuable tool for analyzing player interaction within games. Research by Duchowski (2017) underscores the potential of eye-tracking to yield insights into cognitive load, attention allocation, and user engagement. When combined with facial recognition software capable of assessing emotional responses, these technologies offer a more holistic perspective on the player experience. This integrated approach enables researchers and developers to observe not only behavioral reactions to in-game events but also the accompanying emotional responses, thereby deepening the understanding of player engagement and immersion.

Emotion recognition through facial expressions has increasingly been adopted as a method for capturing real-time user experiences in gaming environments (Zeng et al., 2007). Martínez-Miranda & Aldea (2005) emphasize that when facial recognition systems are integrated with gameplay data, they can provide valuable insights into players' emotional responses, thereby informing more user-centered game design decisions. These systems serve to bridge the gap between objective gameplay metrics —such as clicks, keystrokes, and in-game actions—and the subjective emotional states of players, resulting in a more comprehensive understanding of user experience during gameplay.

The Role of Process Mining in Game Analytics

Process mining—a technique used to analyze event logs in order to discover, monitor, and optimize processes—has gained increasing relevance in the domain of game analytics (van der Aalst, 2016). When applied to user interaction data, process mining enables developers to uncover latent behavioral patterns, detect gameplay bottlenecks, and identify critical friction points in the user experience. Research by Estupiñán and Szilas (2019) demonstrates that process mining can be effectively utilized to analyze gameplay logs, thereby improving game flow and enhancing player engagement. The integration of process mining with emotional data, as proposed in this study, represents a novel approach to understanding the dynamic interplay between gameplay mechanics and user affective responses.

Process mining has proven particularly effective in identifying the underlying mechanisms that shape user behavior. In gaming contexts, it has been employed to elucidate patterns in player progression and interaction (Ramadan et al., 2019). This analytical capability allows developers to visualize user journeys, pinpoint moments of difficulty or disengagement, and make data-informed design adjustments. When combined with eye-tracking and facial recognition data, process mining can support the development of more adaptive and emotionally responsive game systems, where elements such as difficulty levels or in-game content dynamically adjust in real time based on the player's emotional state and behavioral cues

Recent Technological Innovations in Game Design

The evolution of game design technologies has played a pivotal role in shaping contemporary gaming experiences. The integration of artificial intelligence (AI), machine learning (ML), and procedural content generation algorithms into game analytics has introduced innovative methods for predicting player behavior and dynamically adapting gameplay (Liapis et al., 2015). AI-powered adaptive systems are capable of modifying game environments in real time to align with individual players' skill levels and emotional states, thereby enhancing engagement and overall user satisfaction.

AI-driven frameworks, such as those described by Yannakakis and Togelius (2018), are increasingly employed to model player behavior and affective responses, enabling the development of more personalized and immersive gameplay experiences. By leveraging large-scale player data, these systems can predict not only in-game actions but also emotional reactions, facilitating a more responsive and nuanced interaction between the player and the game environment. As a result, gaming experiences are becoming increasingly sophisticated, capable of responding to both explicit player input and implicit emotional cues (Zhang et al., 2022).

As this review indicates, the integration of advanced analytics—including eye-tracking, facial recognition, and process mining—marks a promising frontier for deepening the understanding of player experience. The key challenge lies in developing cohesive analytical frameworks capable of synthesizing these diverse data sources to produce real-time, actionable insights. The convergence of behavioral and emotional data through technologies such as eye-tracking, facial recognition, and process mining offers a novel and robust approach to capturing player experience. Looking ahead, the development of integrated systems that harness these technologies may significantly influence the future of interactive and immersive game design.

Materials and Methods

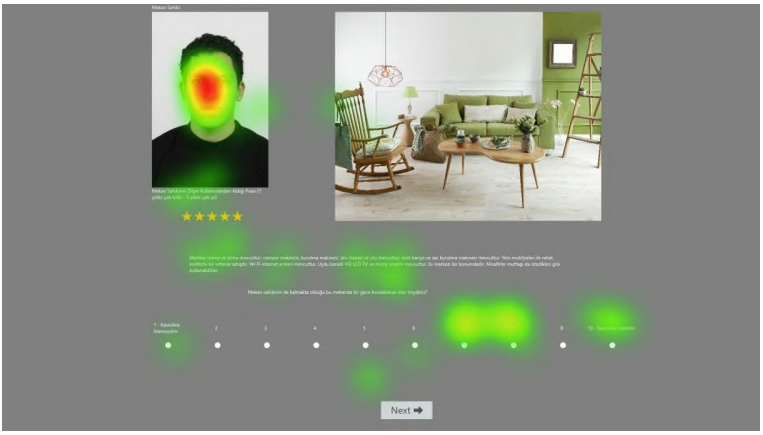
This section outlines how the proposed approach will be integrated into the overall design, following the identification and analysis of its individual components

Collection of Eye and Face Tracking Data

Facial muscle movements and their associations with emotional states were systematically categorized in the seminal work of Ekman and Friesen (1978), which led to the development of the Facial Action Coding System (FACS) (Ekman et al., 2022). FACS enables the identification of specific facial expressions that correspond to distinct emotional responses. Concurrently, eye-tracking technology facilitates the precise recording of users' gaze behavior on the screen by capturing the exact points of visual attention through screen coordinates. An illustrative heatmap generated from such gaze data in a previous study ispresented in Figure 3 (Erden et al., 2021).

Figure 3

The heat map of the raw eye-tracking data for a single screen



Source: Erden et al., 2021:16

During the data collection phase, a sample 2D platformer game developed using the Godot game engine will be employed. While participants engage with the game, eye-tracking data will be collected via a Tobii Eye Tracker 5 device, and facial expression data will be recorded using a Logitech BRIO UHD 4K webcam. The game will be run on a computer equipped with an NVIDIA RTX 3060 graphics card, an Intel i7 processor, and 32 GB of RAM, operating on Windows 11. Participants will be seated approximately 60 cm from a computer monitor with a resolution of 1920×1080 pixels and a refresh rate of 100 Hz.

Eye-tracking data for each participant will be recorded through software integrated directly into the game. This data, which captures the point of gaze as a two-dimensional coordinate (x, y) over time, can be formally represented as a time series: t: $X = \{(x_0, y_0, t_0), (x_1, y_1, t_1), \ldots, (x_n, y_n, t_n)\}$.

To ensure the accuracy of eye-tracking data, a 9-point calibration procedure will be conducted prior to gameplay. During this calibration phase, the eye-tracking device will display nine points on the screen arranged in a grid pattern, including the center, corners, and midpoints of each edge. Participants will be instructed to fixate their gaze on each point as it appears sequentially. This step is essential for accurately determining the direction of gaze, as the device records the position of the participant's eyes relative to the screen coordinates. The data collected from this phase will be used to construct a mapping function that aligns eye positions with screen locations. Following calibration, a validation step will be performed by displaying additional points to confirm the precision of the gaze estimation. This process ensures reliable gaze tracking across the entire screen during gameplay.

Concurrently, facial expression data will be captured at 500-millisecond intervals using the Logitech BRIO UHD 4K webcam. These images will be processed by a parallel application that classifies facial expressions into one of seven emotional categories: anger, fear, neutral, sadness, disgust, happiness, and surprise. Each detected emotion will be time-stamped and stored in a database for subsequent analysis.

To maintain data integrity, instances where the participant momentarily looks away from the screen will be accounted for. In such cases, the eye-tracking device typically records a coordinate value of zero. Therefore, all gaze data will be examined at each timestamp, and entries with x or y values equal to or less than zero will be excluded from the analysis.

By integrating eye-tracking and facial recognition systems, this framework enables the mapping of emotional states to specific moments in gameplay, thereby offering insights into how players emotionally respond to in-game events over time (Henderson et al., 2013; Nuthmann et al., 2010)

Collection of Gameplay Data

One common data collection method employed by game developers involves embedding code into the game to capture in-game behaviors and interactions. However, a significant limitation of relying solely on this type of data is the inability to assess how the player actually feels during gameplay. While traditional methods such as post-play interviews and surveys are often used to gather emotional insights, these approaches present notable drawbacks. They are subject to recall bias and may fail to accurately capture the player's emotional state at the time of the experience. Moreover, players often struggle to articulate their in-game emotions retrospectively, which has been a frequent point of criticism in user experience research.

Data Analytics

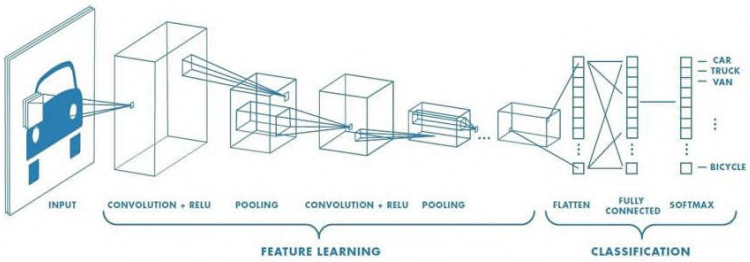
Data capturing players' emotional states during gameplay—based on facial expressions and immersion levels—will also be collected. By integrating this data into deep learning models, such as neural networks, an intelligent system can be developed to analyze users' facial expressions in real time. The origins of deep learning can be traced back to the influential work of Hinton and Salakhutdinov (2006), with convolutional neural networks (CNNs) being among the most widely adopted architectures due to their high efficacy in image recognition and classification tasks (Bi et al., 2021; Moses et al., 2022).

The fundamental operation of CNNs involves preprocessing the input image matrix, extracting salient features through convolutional layers, and classifying these features via fully connected layers. Similar to traditional machine learning methods, CNNs undergo training and testing phases. During training, the network's parameters are iteratively updated using a labeled dataset to optimize classification performance. In the testing phase, the learned parameters are fixed, and the model's accuracy is evaluated on unseen data.

A key distinction between CNNs and conventional machine learning algorithms lies in the convolutional layers, which autonomously perform feature extraction. These layers apply filtering operations to the input data, generating output feature maps that capture essential patterns relevant to the classification task (see Figure 4). Through these convolutional operations, the CNN architecture learns feature representations that are most effective for solving the problem at hand.

Figure 4

CNN layers



Source: Sucuoğlu et al., 2019:221

Training the CNN Model

The model will be trained using a diverse dataset of facial images annotated with corresponding emotion labels. Publicly available datasets such as FER-2013, AffectNet, and CK+ will be utilized to ensure a wide variety of facial expressions and conditions are represented. Utilizing these datasets ensures that the model is exposed to diverse facial expressions and environmental variations, which enhances its ability to generalize effectively to unseen data by learning from varied examples.

The model's hyperparameters—including learning rate, batch size, number of epochs, and architectural parameters of the CNN (such as the number of layers, filter sizes, and activation functions)—will be optimized using systematic techniques such as grid search or random search. Cross-validation methods, particularly k-fold cross-validation, will be employed to verify the robustness and stability of the selected hyperparameters. The use of cross-validation techniques guarantees that the model's performance remains consistent across different partitions of the data, thus providing a reliable estimate of its generalization capabilities. Optimization of hyperparameters such as learning rate, batch size, and number of epochs plays a critical role in enhancing model performance and convergence.

During the training process, preprocessed facial images will be fed into the CNN architecture, where convolutional layers will perform feature extraction and fully connected layers will execute the classification of emotional states. The network will be trained using backpropagation and gradient descent algorithms aimed at minimizing the loss function, typically categorical cross-entropy, which is appropriate for multi-class classification problems.

Model evaluation will involve multiple performance metrics, including accuracy, precision, recall, and F1-score. Assessing the model across these metrics provides a comprehensive understanding of its effectiveness, highlighting potential biases or weaknesses and ensuring robustness across different emotional categories and data conditions (Naidu et al., 2023).

To mitigate overfitting and enhance the model's generalization ability, a separate validation dataset will be used to monitor performance throughout the training process. Furthermore, regularization techniques such as dropout and data augmentation will be applied. Dropout helps prevent co-adaptation of neurons by randomly deactivating units during training, while data augmentation artificially increases the diversity of training samples through transformations such as rotation, scaling, and flipping. Together, these strategies aim to produce a CNN model that is both robust and reliable, capable of accurately recognizing emotions from facial expressions in diverse and dynamic gameplay contexts.

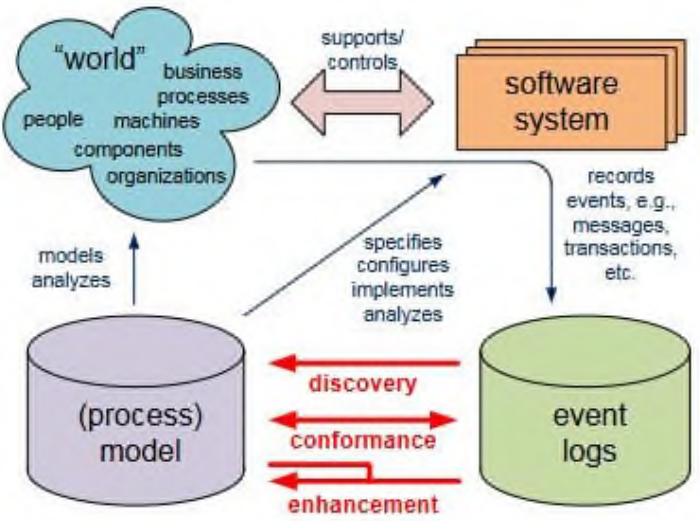
Process Mining

Process mining is a technique that infers underlying processes from event or activity logs and visually represents these processes through graphical outputs. Additionally, it facilitates subsequent analysis by generating process models using heuristic or fuzzy approximations, as illustrated in Figure 5. The primary objective of process mining is to uncover the actual processes recorded within information systems via event logs, enabling discovery, monitoring, and improvement of these processes.

The foundation of process mining lies in event logs, where each event corresponds to a distinct activity. A fundamental assumption of process mining techniques is that events can be recorded sequentially. Each activity is associated with a specific event, and, if needed, supplementary information can be appended to the logs to enrich the analysis. Various software systems capture these event logs, which can then be analyzed through the three main stages of process mining: discovery, conformance checking, and enhancement. This structured approach enables extraction of more meaningful insights from raw event data (van der Aalst et al., 2012).

Figure 5

Positioning of the three main types of process mining: (a) discovery, (b) conformance checking, and (c) enhancement



Source: van der Aalst et al., 2012:174

Ramadan et al. (2019) highlight in their conference proceedings that the graphical representations generated through process mining are particularly effective in illustrating complex, semi-naturalistic behavioral patterns, especially in first-person shooter games. In the present approach, gameplay logs will be integrated with data from analytics software to construct a user-centered process model. This model aims to reveal underlying mechanisms and factors—such as bottleneck points—that influence the structure of the gameplay process.

Implementation

Building on advances in process mining, eye-tracking, facial expression analysis, and deep learning, our proposed system aims to deliver a comprehensive, player-centric framework for adaptive gameplay. By generating detailed process maps that capture diverse user profiles—including behavioral patterns and emotional states—this system will dynamically tailor game experiences to players' varying moods and engagement levels. Designed as an API compatible with leading game engines such as Unity, Unreal Engine, and Godot, the system will facilitate seamless integration for developers seeking to implement real-time, data-driven game adaptation. Inspired by the LiveOps paradigm (Dubois & Weststar, 2021), our approach leverages continuous gameplay analytics and emotion recognition to update game content responsively, thereby enhancing player immersion, satisfaction, and retention. This integration of multi-modal user data and process mining is expected to provide a robust toolset for understanding and optimizing player experience within complex gaming environments.

Results and Discussion

As previously noted, hardware capacities and network connection speeds have significantly increased over the past 25 years. Modern average devices are now capable of simultaneously running both game software and complex analysis tools. Consequently, it is technically feasible to collect gameplay and user experience data directly from ordinary players in real-world settings, rather than

relying solely on data gathered from controlled playtesting environments. This advancement paves the way for transforming the proposed system into a user-friendly, commercial software package, readily accessible to game development companies. While some studies have employed eye-tracking devices (Kiili et al., 2014), to the best of our knowledge, no research has integrated and examined multiple data types—such as eye-tracking and facial expression data—together with process mining. This integration constitutes the unique and fundamental contribution of our proposed approach.

The methodology, which combines eye-tracking, facial recognition, and process mining, offers a comprehensive framework for understanding player experience in video games. Although initial implementation may require considerable resources, the potential benefits—including enhanced game design, increased player engagement, and ultimately higher revenue—can justify the investment.

High-quality eye-tracking devices and cameras can be costly, particularly when multiple units are required for large-scale deployment. Additionally, specialized software for facial recognition, process mining, and data analysis contributes to upfront expenses. Skilled personnel for data collection, processing, and interpretation are also essential, which may increase costs, especially in long-term projects.

However, by gaining deeper insights into player behavior and emotional states, developers can design more engaging and personalized gameplay experiences, reducing the risk of costly iterative development and failure. Tailored gaming experiences lead to greater player satisfaction and retention, thereby increasing revenue. While the initial investment may be significant, the long-term benefits can surpass the costs. For instance, reducing reliance on extensive playtesting and iterative cycles saves both time and resources. The ability to deliver personalized and immersive experiences confers a competitive advantage in the marketplace.

To illustrate the potential return on investment, consider a hypothetical scenario where a game development company implements a comprehensive player experience analysis system. Such a system would enable the company to identify and resolve gameplay bottlenecks that previously caused player frustration and churn, optimize in-game monetization strategies based on behavioral and emotional data, and create personalized content that resonates with specific player segments. These improvements would result in increased player retention and revenue, thereby justifying the initial expenditure.

Although the proposed methodology demands substantial upfront investment, the long-term gains in game quality, player engagement, and financial performance make it a worthwhile consideration for developers. By adopting cost-reduction strategies and leveraging data-driven insights, companies can maximize their return on investment and gain a competitive edge in the evolving gaming industry.

Today's video game industry is highly competitive, and meeting player expectations is increasingly critical. To address these expectations, various technologies have been developed for player data collection and game updates. LiveOps, a relatively recent innovation, enables incremental game updates without the need for large-scale patches. For data collection, user analytics software, surveys, and interviews remain prevalent. Scholars are actively working toward developing standardized and validated surveys to improve data quality (Berkman et al., 2021; Mandasari & Pudjoatmodjo, 2019). Although analytics software provides real-time game data, it often lacks insight into the player's subjective experience. Conversely, surveys and interviews capture user experience but are limited by their retrospective nature, potentially missing real-time emotional responses during gameplay. Industry experts share these concerns (Schell, 2020).

To address these limitations and bridge this gap, we propose an integrated method combining data analytics software, process mining, eye-tracking, and facial expression analysis to capture real-time emotional and behavioral data from players. This integrated system enables the collection of more reliable, immediate data, reducing dependence on retrospective feedback from inexperienced or non-

technical players. Moreover, the speed of data collection and analysis can match the pace of game updates, facilitating enhanced player experiences through timely and informed game adaptations.

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Chapter 16

Sentiment Analysis Using Data Obtained from Twitter

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Abstract

The widespread use of internet technology has caused social networks to have a great place in human life. Individuals who shared about their lives and thoughts provided researchers with a great deal of data for their studies on various subjects. It has been observed that Twitter is widespread, especially since it is text-based in sharing thoughts. The increasing number of shared tweets has caused researchers to encounter a huge data crowd. Since it is not possible to manually analyze or classify this large-scale data, it has become a necessity to analyze and classify it by a system. For this reason, it has been inevitable for researchers to turn to the fields of text mining and sentiment analysis. In this article, the subject of text mining and sentiment analysis is examined together with its details and approaches and presented as a literature review. In the application part, a sentiment analysis study was conducted with the data taken from Twitter on a determined subject.

Keywords Sentiment analysis · twitter · machine learning

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Introduction

The rise of social media, driven by the dominance of Web 2.0 technology in the internet world, continues to increase in popularity. Individuals who dedicate substantial time to social media in their daily lives have become open to both the positive and negative aspects of the evolving digital world (Buzzi et al., 2011; Pak & Paroubek, 2010). Social networks, particularly Twitter, have transformed societal structures and communication methods, influencing the way individuals think and behave in both personal and social matters. In the examination of social networks, it is observed that these platforms offer significant opportunities for researchers to observe, identify, and interpret the thinking patterns of the public (Fermanoğlu, 2020).

One of the most widely used social networks today is Twitter, which stands out in these examinations. Twitter's unique position stems from its ability to allow users to freely express their thoughts on various topics, providing an opportunity for both social researchers and producing companies to infer future preferences (Bermingham & Smeaton, 2011). With over 330 million users worldwide, Twitter has become a platform where over 8,000 tweets are shared per second, according to recent figures (Karabulut & Küçüksille, 2018; Murthy, 2018). Given the current number of tweets shared per second, the magnitude of the obtained data is particularly noteworthy.

Since its inception in 2006, Twitter has increasingly become an integral part of individuals' lives worldwide. Especially by offering publicly accessible data, Twitter contributes significantly to text mining researchers. Researchers can easily access content that has not been restricted by users, allowing them to complete their studies based on a defined problem and reach various results.

In research, Twitter has been recognized for having its own language, causing challenges in understanding the existing data due to reasons such as misspelled words. As a result, various studies related to natural language processing and data mining have been initiated, and industry products have been introduced using these methods (Ayan et al., 2019).

Two prominent methods in the process of processing Twitter data and making it understandable and analyzable are text mining and sentiment analysis. Text mining is utilized in making the obtained data understandable, while sentiment analysis is employed in the analysis of data and obtaining a result.

Twitter, by offering users the opportunity to express themselves with words rather than visual posts, has become a platform where ideas are shared in various fields, from politics to psychology, from movies to music albums, from customer experiences to business life, and even daily life problems. At this point, sentiment analysis plays a crucial role in determining subjective information such as emotions, opinions, and attitudes, enabling strategic decisions in marketing, predicting financial ratios, customer churn analysis, determining industry opportunities and threats, and pre-determining competitors' activities based on the data compiled with text mining (Onan, 2017).

Matrix of Literature Review for the Findings of the Study

A total of 20 articles within the scope of the study were examined by two researchers (graduate students). Studies on Twitter sentiment analysis were analyzed based on the approaches they employed. The examinations were organized in terms of authors, year of publication, dataset used, approach, algorithm, and results. The results are summarized in Table 1.

Table 1

Findings Reached Through Literature Review on Approaches to Twitter Sentiment Analysis

Yazar	*Yıl*	*Veri Seti*	*Yaklaşım*	*Algoritma*	*Sonuç*
Sarah E. Shukri, Rawan I. Yaghi, Ibrahim Aljarah, Hamad Alsawalgah	2015	Data from 1000 Twitter posts	Dictionary-based	Naive Bayes (NB)	The study's findings indicate that the percentage of joy is higher for BMW compared to Mercedes and Audi, while the percentage of sadness is higher for Mercedes and Audi when compared to BMW.
Prerna Mishra, Dr. Ranjana Rajnish, Dr.Pankaj Kumar	2016	Twitter data expressing opinions on the subject	Dictionary-based	SentiWord	The analysis results indicate that opinions and thoughts are observed to be 50% positive, 20% negative, and 30% neutral.
Laila M. Qaisi, Ibrahim Aljarah	2016	Twitter and cloud systems data	Dictionary-based	Naive bayes (NB)	At the conclusion of the study, it was observed that in the positive category of joy, Microsoft Azure is in a better condition compared to Amazon, and Amazon has a higher percentage of negativity.
Entesar M. Milod Eljali	2019	50,000 Twitter data obtained from 5 different Twitter accounts	Dictionary-based		This thesis study has provided a significant contribution to the literature by offering important information flow. Particularly, the development and introduction of a useful tool, based on new empirical methods, for identifying potential emotional reasons in the emotional flow of a specific user has been a key aspect of this contribution
Hatice Kübra Küçükkartal	2020	10,000 English Twitter data	Dictionary-based		As a result of sentiment analysis, the posts made by individuals on the subject were analyzed to determine whether they were positive, negative, or neutral. The findings reveal that approximately 42% of the tweets are positive, 14% are negative, and 43% are neutral.
Marco Pennacchiotti, Ana-Maria Popescu	2011	Twitter data expressing opinions on the subject	Machine learning-based	Gradient Boosted Decision Trees (GBDT)	The analysis results indicate that the study has largely achieved its purpose and obtained positive outcomes.

Hao Wang, Dogan Can, Abe Kazemzadeh, François Bar, Shrikanth Narayanan	2012	Simultaneous Twitter data expressing opinions on the subject	Machine learning-based	Naive bayes (NB)	As a result, a real-time system has been developed for the ongoing elections, where Twitter data is analyzed in real-time.
Geetika Gautam, Divakar yadav	2014	Twitter data.	Machine learning-based	Naive bayes(NB), maximum entropy(MaxEnt), support vector machines(SVM)	The study has contributed to the literature by conducting a comprehensive data analysis.
Hatice Nizam, Saliha Sıla Akın	2014	Two separate Twitter datasets created with a total of 2824 tweets	Machine learning-based	Naive Bayes (NB), Sequential Minimal Optimization (SMO), Decision Tree (J48), Random Forest (RF) and 1-Nearest Neighbors (IB1)	The experimental results revealed that the balanced dataset, exhibiting an appropriate distribution among the results, outperformed the imbalanced dataset. According to the analysis, the classification algorithm that demonstrated the best performance was SMO with an average accuracy rate of 72.33%.
Önder Çoban, Barış Özyer, Gülşah Tümüklü Özyer	2015	20,000 Twitter data, consisting of 10,000 positive and 10,000 negative entries	Machine learning-based	SVM, Naive Bayes, Multinom Naive Bayes and KNN	This study, based on the findings obtained, confirms the thesis that experimental results show Twitter messages can be classified using machine learning methods.
Yağız Nalçakan, Şan Sıtkı Bayramoğlu, Samed Tuna	2015	Three separate Twitter datasets comprising 1500 tweets each about Samsung, Apple, and LG	Machine learning-based	Naive Baye(NB), Random Forest(RF), LibSVM, J48 and KStar	When all the results are examined, it has been decided to work with a larger dataset to find a meaningful result. Nevertheless, evaluating the results obtained, it can be seen that in both studies, the Naive Bayes (NB) algorithm yielded the best results among the three companies.
Varsha Sahayak, Vijaya Shete, Apashabi Pathan	2015	Twitter data expressing opinions on the subject	Machine learning-based	Naive bayes(NB), maximum entropy(MaxEnt), support vector machines(SVM)	The result of the study is positive feedback from survey results. In other words, participants have concluded that the data from Twitter would be effective in sentiment analysis.

Tuba Parlar, Esra Saraç, Selma Ayşe Özel	2017	A total of 3000 Twitter data belonging to three different classes (positive, negative, neutral)	Machine learning-based	Maximum Entropy Modeling (MEM)	According to the results of the study, it has been observed that feature selection has significantly positive effects on classification performance. Reducing the number of features not only enhances classification performance but also sharply decreases the classification time. This indicates that feature selection is an available method for improving the overall performance of the system.
Aytuğ Onan	2017	A total of 10,600 Twitter data, comprising 5,300 positive and 5,300 negative entries	Machine learning-based	Naive Bayes classifier (NB), Support Vector Machines (SVM), and Logistic Regression (LR)	As a result of experimental studies, the highest performance (%77.78) is achieved when the feature set is represented by combining 1-gram and 2-gram feature sets, and the Naive Bayes algorithm is used as the classification algorithm.
Buğra Ayan, Birol Kuyumcu, Bünyamin Ciylan	2019	Twitter data obtained in the English language	Machine learning-based	Linear Ridge Regression and Naive Bayes	According to the analysis results, for positive tweets, better outcomes were achieved in the Ridge model compared to the Naive Bayes classifier. In Ridge Regression, a accuracy rate of 96.3% was reached, while in the Naive Bayes Classifier, the accuracy rate was 95.3%.
Cihan Çılgın, Ceyda Ünal, Serkan Alıcı, Ekin Akkol, Yılmaz Gökşen	2020	Twitter data expressing opinions on the subject	Machine learning-based	Artificial Neural Networks, Logistic Regression, Support Vector Machines, and Naive Bayes	The analysis revealed a correlation coefficient of 0.681, indicating a moderately strong positive relationship.
Haruna Isah, Paul Trundle, Daniel Neagu	2014	Twitter and Facebook data	Hybrid	Naive bayes (NB)	The analyses resulted in positive outcomes.
Eyüp Sercan Akgül, Caner Ertano, Banu Diri	2015	Three separate Twitter datasets with 500 tweets (VS1), 1200 tweets (VS2), and 5100 tweets (VS3)	Hybrid		The dictionary-based and character-based n-gram methods achieved success rates of approximately 70% and 69%, respectively. It was observed that the dictionary-

					based approach yielded more successful results.
Thakare Ketan Lalji, Sachin N. Deshmukh	2016	Twitter data expressing opinions on the subject	Hybrid	Support Vector Machine (SVM)	According to the results, the dictionary-based approach demonstrated high precision when used alone, but performance issues were observed. The researchers enhanced performance efficiency by combining it with a machine learning-based approach.
Harisu Abdullahi Shehu	2019	13,000 Twitter data	Hybrid	Random Forest and Support Vector Machines	The analysis results indicate that Support Vector Machines have the shortest execution time, the Random Forest method performs better on raw data, and the performance of the method using a polarity dictionary improves in a way not observed in other methods.

In reviewing the table, it is observed that the first study on sentiment analysis on Twitter in the literature was conducted by Pennacchiotti and Popescu (2011). Subsequently, one study continued in 2012, and between 2014-2015, 8 studies were conducted, followed by 5 studies between 2016-2017, and 4 studies between 2018-2020.

When looking at the datasets used in the examined studies, it is seen that in 18 studies only Twitter data was used, and in the remaining 2 studies, a dataset created by combining Twitter and Facebook or Twitter and cloud systems data was preferred. The tweets contain individuals' opinions and emotions on relevant topics in their entirety.

When the examined studies are analyzed based on the approaches they rely on, it is observed that 5 dictionary-based, 11 machine learning-based, and 4 hybrid approaches were preferred. From these results, it can be seen that machine learning-based approaches were predominantly used.

When evaluated according to the classification algorithms used, Naive Bayes (NB) was used in 12 studies, Support Vector Machine (SVM) in 8 studies, Maximum Entropy (MaxEnt) in 3 studies, Random Forest (RF) in 3 studies, Logistic Regression (LR) in 2 studies, Decision Trees (J48) in 2 studies, Gradient Boosted Decision Trees (GBDT), knn, kstar, Sequential Minimal Optimization (SMO), Linear Ridge Regression, 1-Nearest Neighbors (IB1), artificial neural networks, and Multinom Naive Bayes classifiers were used in 1 study each. As seen, Naive Bayes (NB) and Support Vector Machine (SVM) classification algorithms were predominantly preferred.

In general, the overall result of the studies indicates that sentiment analyses conducted on Twitter provide quite positive results in determining what individuals think about various topics, being effectively utilized.

Materials and Methods

The common feature of patriarchal societies in many regions of the world, including Turkey, is that the place of women in society shows similarities. Women, who have been kept in the background in patriarchal societies from the past to the present, have started to actively participate in all areas of life and live freely in every sense with the integration of civilization into life and modernization. During this transition process, the issue of violence against women, a common feature in patriarchal societies around the world, has become more audible, especially with the development of technology and social media, and the reactions given at this point have become visible to everyone.

The main idea of this study is to evaluate tweets about "violence against women" during a specified period on Twitter, one of the largest social media platforms where people express their thoughts verbally, and to classify these ideas as positive/negative using sentiment analysis method.

Methodology

Under this heading, the structure and quantity of the data used in the study, along with the data collection and cleaning stages, have been discussed, with a final emphasis on the sentiment analysis section. A dictionary-based approach was employed for the analysis.

Dataset

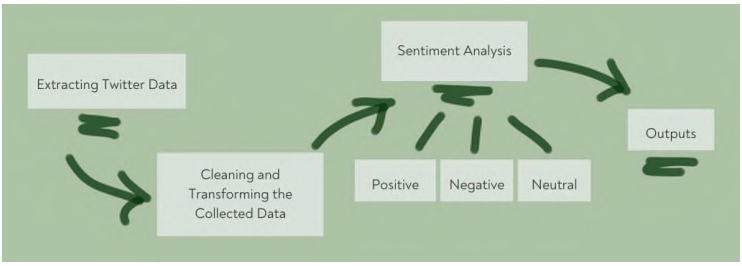
Python programming language was chosen to collect data from Twitter. Tweets containing the keyword "kadinasiddet" (violence against women) were collected. For these operations, the Selenium module was used, which allows the automation of browser actions, such as opening a browser like Chrome or Firefox with driver support installed on the computer, to simulate human-like interactions through programming language. In the context of the application, 819 tweets posted between 2010 and 2019 were accessed using the Firefox browser.

Data Preprocessing Steps

Twitter denotes user names with the "@" character and hashtags with the "#" character. In the process of cleaning the data, these characters are initially removed from the tweets. It is essential for the tweets to undergo this preprocessing step before the classification process. In this study, this process was carried out using the NLTK library in Python. Starting with these characters, the top 30 stop words determined for Turkish were removed to facilitate the analysis stage. In summary, initially, all uppercase letters in the collected tweets were converted to lowercase. Then, non-alphabetic characters were removed from the tweets. Subsequently, user names, hashtags, and URL addresses in the tweets were cleaned, and finally, stop words were removed, leading to the analysis stage.

Figure 1

Sentiment Analysis



In sentiment analysis, dictionaries such as HowNet (Fu et al., 2017), SentiWordNet (Montejo-Ráez et al., 2014), and MPQA (Saif et al., 2016) are used in various regions of the world. In this study, SentiTurkNet was employed as the dataset for Turkish sentiment analysis. SentiTurkNet contains 15,000 words and word sets, each with three separate polarity scores for positive, negative, and neutral sentiments. In the study, the words in each tweet collected from Twitter were compared with the words in the SentiTurkNet dataset to determine the polarity and polarity score of each word. Following this stage, as shown in Figure 1, each tweet was analyzed based on the collected polarity score and the negative/positive/neutral status. The score values were determined according to the number of positive and negative words in the tweets.

Conclusion

In this study, research on text mining and sentiment analysis was examined, and the results were evaluated based on the approaches used. The concepts of text mining and sentiment analysis were explained in detail in the study, presented in a language that can be understood by anyone, including readers and researchers who are new to the subject. Additionally, three methods used in sentiment analysis were explained.

When examining research on machine learning-based approaches, it was observed that generally two or three datasets were used. Typically, these datasets are separated into training and testing datasets. When machine learning-based approaches were used in the research, it was observed that more reliable results were obtained, and the approach allowed predictions for the future, assisting in making strategic decisions related to the subject. In research comparing classification algorithms used in this approach, Naive Bayes algorithms were found to provide more successful results.

In the dictionary-based approach, researchers have two options for the database. When a ready-made database is selected, the sentiment scores valid for that database are taken into account. Another option for researchers is to create their own corpus. In corpora, words and sentiment scores are determined by researchers. In the articles examined on the dictionary-based approach, it is mostly observed that a ready-made database is preferred. This approach is generally used to uncover information about the sentiments expressed by words used in the study related to the examined subject, whether they are positive, negative, or neutral. In articles, the dictionary-based approach is often seen to prefer weighting with TF-IDF (Term Frequency - Inverse Document Frequency). Research results provide positive, negative, and neutral ratios.

In the hybrid approach, both the dictionary-based and machine learning-based approaches are used. The machine learning-based approach is included when the dictionary-based approach is used and is insufficient. In research using this approach, it was observed that the dictionary-based approach yielded more successful results when compared to the machine learning-based approach. In another study, it was observed that the dictionary-based approach showed high accuracy when used alone but faced performance issues, and when used in conjunction with the machine learning-based approach, it improved performance. These two cases show that the successful approach in the hybrid approach depends on the research's goal.

When all the articles examined in this study are evaluated, it is seen that each of the three approaches can be used depending on the research's goal. The desired results were achieved in sentiment analyses of data collected from Twitter. It was clearly observed that researchers could use sentiment analysis in solving problems related to their areas of interest. Additionally, it was revealed that sentiment analysis would shed light on various research topics in the future, such as social events, customer analyses for companies, and the examination of individual personality traits.

In the final section of the study, tweets containing 'kadinasiddet' (violence against women) posted on Twitter within a specific date range were examined using the data collected from Twitter. The dataset obtained by extracting data from Twitter was evaluated through sentiment analysis, and scores were determined. According to the sentiment analysis, out of 819 tweets posted between 2010 and 2020, 71 were scored positively, 145 received negative scores, and 341 were neutral. The remaining tweets were not used after preprocessing.

In conclusion, with the data obtained in this study, it is possible to examine when society expresses its views on 'violence against women' more in certain periods through social media, when more negative results are obtained, and when the data follows a normal course. As a more comprehensive study, starting a new study with high processing power and conducting research on visual and video content tweets using image processing libraries can be considered. Finally, by adding the location factor, tweets can be listed, and tweets about 'violence against women' for different locations and countries can be examined.

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Chapter 17

Smart Human at the Focus of Technological Intelligence in the Smart City

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Abstract

According to the United Nations World Urbanization Prospects Revised Report, more than two-thirds of the world's population is expected to live in cities by 2050. Planning and implementing comprehensive infrastructure have become top priorities for cities to cope with increasingly overcrowded populations. One of the solutions to this problem is the concept of a smart city, which has a technological infrastructure and consists of various components, which was introduced after the 1990s. For a city to be considered 'smart,' all its stakeholders and components must communicate correctly and consistently with each other. This regular and rapid communication is facilitated by the intelligence of each component—Economy, Environment, Government, Living, Mobility, and Smart People (Human). The development of artificial intelligence and cloud technologies is accelerating communication much more. The connections between machines and humans and machines and other machines are causing smart cities to transform into formations that think and act like biological humans. Intelligence is needed to use and develop this constantly developing technological life in a smart city. Is this technological intelligence embedded in a smart human? In this study, the importance of the smart human element in the communication of smart city components and the sustainability of smart city services will be highlighted based on studies conducted on this subject, and the role and significance of the smart human in the future will be emphasized.

Keywords Smart city · smart human · technology · artificial intelligence

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Smart City

Cities are living spaces where people have to live in crowded environments, requiring a wide range of infrastructure and administrative planning, where speed and modernity come together. Urbanization has been ongoing for many years in upper- and middle-income countries all over the world. While only 22% of the population lived in urban areas in the 1950s, it is predicted that this rate will reach 83% in the 2050s. Traffic, transportation, disaster and accident prevention, crime prevention, educational activities, child and elderly care, energy consumption, waste management, and other issues directly or indirectly concern all stakeholders of the city. Rapid urban development can bring many risks that may exceed the ability to provide adequate services to city residents (Neirotti et al., 2014). This crowded population in cities has paved the way for the formation of smart cities with the help of technology. The concept of "Smart City" first emerged in the 1990s. In the early years, the focus was on the adaptation of new Information and Communication Technologies (ICT) to modern infrastructures in cities. The California Smart Communities Institute focused on how a city can be planned to implement information technologies and how communities can become smart (Alawadhi et al., 2012). In the early days, it was thought that it would take many years for smart cities to come to life, but the "smartness" of the city has been integrated into daily life very quickly, and city intelligence continues to develop continuously. Cohen (2015) divided the development of smart cities into three generations. After the technology-focused smart cities called the first-generation, the second-generation smart cities, which are city-focused but technology-enabled, have emerged. Concilio et al. (2014) state that the second-generation smart city transformation is the result of the interaction between top-down and bottom-up forces, urban resources (spatial, social, political, economic, infrastructure and cognitive), and transformation opportunities. It has been seen that the need to find creative solutions to existing and foreseeable problems in smart cities has increased over time (human dimension and the future of smart cities) and the importance of the role of citizens has emerged. Third-generation smart cities are defined as cities where the concept of "citizen/human co-creation" is adopted. It is aimed to further increase the quality of life by creating sustainable and interactive sharing cities with the latest generation of smart cities.

There are many approaches to defining smart cities. Although these approaches are different from each other, the common point is that it is not possible to talk about a smart city without technological infrastructure and information and communication networks. The most integrated of the current approaches to smart cities is based on advancing and realizing both the urban future and the knowledge and innovation economy (Angelidou, 2015). A smart city is the interconnection of physical, social, ICT, and commercial asset-based infrastructure to estimate the total intelligence of the city (Gülseçen et al., 2013). According to Giffinger et al. (2007) and Cohen's (2013) smart city wheel methodology, which is also accepted by the European Union, smart cities consist of six components; Smart governance, Smart people (humans), Smart environment, Smart economy, Smart life, Smart transportation/movement. Each of these main components can be used for other smart elements such as smart buildings, smart security, smart health, smart environment, etc. Each of the main and sub-components turns into smart elements in a smart city. All smart city frameworks in the literature consist of multi-dimensional systems. Table 1 provides a summary of the basic components/dimensions of the smart city concept commonly mentioned in the literature (Castelnovo et al., 2015).

Table 1
Smart city components/dimensions (Castelnovo et al., 2015)

Smart city components/dimensions	Examples
ICT, Communication, Intelligence, Information	Hoon Lee et al., 2013; Washburn et al., 2010; Giffinger et al., 2007; Dirks & Keeling, 2009; ITU, 2014; Caragliu et al., 2009
Governance, Management & Administration	Meijer & Bolívar, 2013; Chourabi et al. 2012; Lombardi et al., 2011; Caragliu et al., 2009; Nam & Pardo, 2011; Batty et al., 2012; Scholl & Scholl, 2014
Quality of Life & Lifestyle	Lombardi et al., 2011; Giffinger et al., 2007; Caragliu et al., 2009; Batty et al., 2012; Ballas, 2013; Neirotti et al., 2014; Shapiro, 2006
Infrastructure and Services	Washburn et al., 2010; Batty et al. 2010; Nam & Pardo, 2011; Dirks & Keeling, 2009; Lombardi et al., 2011
People, Citizens, Society	Lombardi et al., 2011; Giffinger et al., 2007; Chourabi et al. 2112; Shapiro, 2006; Hoon Lee et al., 2013
Environment and Sustainability	Giffinger et al., 2007; Lombardi et al., 2011; Nam & Pardo, 2011; Roseland, 1997; Kourtit et al. 2013; Bătăgan, 2011
Economy and Financials	Caragliu et al., 2009; Ballas, 2013; Bătăgan, 2011; Lazaroiu and Roscia, 2012
Mobility	Neirotti et al., 2014; Lombardi et al., 2011; Giffinger et al., 2007; Caragliu et al., 2009; Dirks and Keeling, 2009; Washburn et al., 2010

The most important feature of smart cities is the preservation and continuity of sustainability. In the 21st century, human civilization accepts the connection between globalization and urbanization as the main driving force of sustainable development (Agbali et al., 2019). New trends accept that citizens are the ones who give the city the opportunity to be considered smart. This trend promotes sustainability through interaction with citizens and digital spaces (Carrasco-Sáez, et al., 2017). The aim of smart city structures is to ensure sustainable development, and maximize the life security and competitiveness of a city (Wu et al., 2019). Bakıcı et al. (2013) state that the aim of a smart city is to offer its citizens the highest possible urban life quality. Smart cities are considered an indicator of development for countries due to their contribution to the increase in the service quality of the city, its sustainability, and the economic growth of the countries in the long term. This situation also leads to cities competing with each other on a global scale on the way to becoming smart cities. In developed countries, cities that best implement smart city technologies include London, Stockholm, Dubai, New York, Barcelona, Hong Kong, Amsterdam, Singapore, Tokyo, Paris and Copenhagen (Lai et al., 2021).

Technological Intelligence in Smart City

A smart city consists of three basic components; technology factors, and human factors and organizational factors (Nam and Pardo, 2011). In smart cities, technology plays an important role beyond the traditional goals of optimizing city management services and improving the quality of life; the role of communication. Smart cities use ICT to collect and transmit information to different users in the city and apply the information obtained when necessary to achieve smart goals. Devices and platforms such as the Internet, wireless networks, sensors, mobile phones and cloud computing are some of the actors that constitute ICT. For a city to be smart, all its components must be in correct and regular communication with each other. A smart city is a city where ICT is used in the lives of individuals in many areas from economic regulation to social management, from public services to market control.

The use of ICT in city planning and management, the connection of people living in those cities to the city with electronic public services, and the establishment of communication networks contribute to the increase in the competitiveness of the city and the quality of life of its citizens. Information infrastructure is the lifeblood that provides healthy communication and vitality in smart cities. In a smart city, devices using ICT communicate with each other and people, process data, store it, transmit it when necessary, and work to transform it into useful information. Applications that provide information such as road and traffic conditions, weather conditions, air quality, etc., which are frequently used in daily life for smart city residents, make life easier. On the other hand, data such as human and vehicle mobility tracking in the city, weather monitoring, waste management, etc. are very valuable sources of information for city managers and planners. Monitoring, collecting, storing, and transforming this data into meaningful information is used for long-term planning in smart cities.

The development of smart cities is strongly linked to information technologies such as cloud computing, mobile devices, the semantic web, and the Internet of Things (Lytras and Visvizi, 2018). Artificial intelligence (AI) technologies have made a rapid entrance into these concepts in recent years. According to Al-Turjman (2017), the most important and distinct component of most smart city applications is the Internet of Things, which is responsible for generating enormous amounts of data. The concept of the Internet of Things, known by the abbreviation IoT, refers to technological devices communicating with each other through networks and sensors. Al-Fuqaha et al. (2015) define IoT as the process of enabling physical objects to "talk" to each other, see, hear, think, and perform tasks, share information and coordinate decisions. IoT transforms objects from traditional to "smart" by using basic communication technologies such as devices, sensor networks, internet protocols, and applications embedded with a ready and widespread computing infrastructure in every field. IoT is also a communication network consisting of software and access services that enable the control and analysis of physical events in private living spaces. These events can be measurable and countable quantities, image, motion and sound sensors interconnected in areas such as home and business life, shopping, traffic and health, etc. Technologies used in smart buildings, smart kitchen appliances, blinds working with light-sensitive sensors, smart lighting devices, smart air conditioning systems, smart technological devices working sensitive to heat and sound, etc. are all members of the IoT family.

Artificial Intelligence (AI) Technology in Smart City

In the presence of the large, complex and ever-increasing big data capacity of smart cities, it is not easy to make the most accurate and effective decisions. Big data is a technology for making sense of raw and scattered data. It provides benefits to managers in decision-making and prediction (Duman & Akdemir, 2021). Reaching an optimum decision with the best possible analysis of big data can be achieved using advanced techniques such as AI, Machine Learning (ML), and Deep Reinforcement Learning (DRL) along with traditional methods (Liu et al., 2019). Artificial intelligence brings together various technologies that enable software, systems, machines and devices to learn from their own experiences, perceive, develop, understand or perform human activities with extraordinary performance (Ahmed et al., 2022). AI is an important part of many advanced technologies, including robotics, self-driving cars, humanal assistants such as Apple's SIRI, web searches, consumer preference determination, and video games. Kaplan and Haenlein (2019) define AI as “the ability of a system to correctly interpret external data, learn from such data, and use such learning to achieve specific goals and tasks through flexible adaptation” and divide them into three types: analytical, human-inspired, and humanized. Analytical AI is consistent only with cognitive intelligence. Human-inspired AI has emotional intelligence, that is, understanding human emotions, and using them to make decisions, in addition to cognitive intelligence. Humanized AI includes social intelligence in addition to the first two types of AI and can be self-

aware in its interactions and exhibit characteristics of all types of competencies (cognitive, emotional, and social intelligence).

Artificial intelligence uses data processing and algorithms to extract meaningful information and increase the intelligence of machines over humans (Hardoon & Shmueli, 2013). With the rise of cloud computing and artificial intelligence technology, governments have tended to use data analytics through artificial intelligence to create more value (Gao & Janssen, 2020). AI can analyze data generated in real-time in the past and make meaningful predictions from them. It is expected that the prediction accuracy will increase at the same rate as the amount of data used by artificial intelligence increases. The rapid development of ICTs such as big data and cloud computing is maturing and expanding the scope of artificial intelligence technology. With the increasing population in smart cities and the spread of ICT use to wide areas, the number of data generated is increasing exponentially. Smart applications used by citizens with personal mobile devices such as mobile phones, geographic information systems, urban transportation information systems, location information, social and cultural space information, etc. increase the data size in smart cities. ICT, IoT, and AI have a large intersection area that supports and develops each other. The use of ICT and IoT can become intelligent in smart cities, becoming the artificial intelligence of objects and transforming into the artificial intelligence of objects (AIoT = AI + IoT) (Dong et al., 2021).

Governance in smart cities, smart buildings, health monitoring, education, security and privacy, smart transportation, energy efficiency, etc. are some of the areas where artificial intelligence is used (Voda & Radu, 2019). One of the important problems of big cities is air pollution. Poor air quality can cause problems related to human health, energy efficiency, transportation, and different business areas related to them. Data obtained using AI, IoT, and cloud computing can guide urban air quality management in making the right decisions to control and manage urban emissions. (Lee, 2020; Kaginalkar et al., 2021). One of the many artificial intelligence studies used in the field of health is the artificial intelligence-supported health monitoring technology models, which are specially adapted for the disabled or elderly in disadvantaged groups and are extremely useful in pandemic conditions (Rathi et al., 2021).

While traditional AI applications based on predefined algorithms and data sets play a significant role in improving various systems in smart cities, the emergence of Generative Artificial Intelligence (Generative AI) has created a revolutionary effect. This transition from traditional AI to Generative AI in smart cities provides more adaptable, creative, and efficient responses to urban challenges, paving the way for smarter cities. With the Generative AI effect, the acceleration of services in areas such as traffic management, energy distribution and public safety is increasing, paving the way for previously unimaginable innovations. At the same time, a wide range of complex problems in smart cities can be evaluated with unprecedented sensitivity, down to personalized solutions (Avcı, 2024).

Smart city administrations also create open data platforms with data-sharing services. Big data technologies enable the collection of large amounts of data, and artificial intelligence technologies can analyze this data with high speed and high accuracy. Citizens' access to, sharing, and use of data means accountability and transparency of the administration. These datasets consist of historical and real-time sources for further research and development. The open data government movement encourages citizens to have transparent governance and participation. The use of data helps to increase public value by creating innovation (Janssen et al., 2012). In parallel with their technology-driven development, in recent years, importance has been given to research on the peace and happiness of smart cities for their residents. In the studies carried out, the understanding of human happiness and social well-being in urban life is taken into account. The "Happiness Agenda" implemented in Dubai can be given as an example of human-centered smart city development studies for "happiness" on the way to becoming "the happiest city in the world" (Zakzak, 2019).

Smart Human

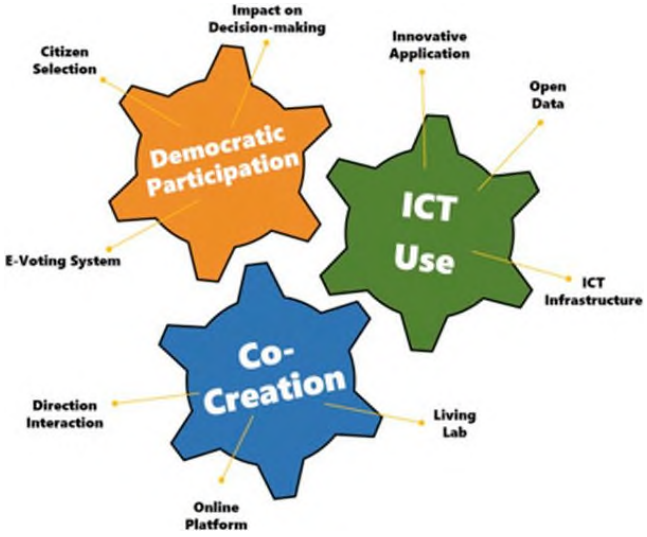
Although the technological aspects of smart cities are well addressed in the literature, the fundamental role of citizens in these cities has often been neglected (Visvizi et al., 2018). The information age that developed all over the world after the 1980s brought with it a global digital transformation. Digital transformation paved the way for individuals in the information society to gain a digital identity. Thus, the concept of "digital citizenship" emerged in the world. It can be said that the concept of digital citizenship paved the way for the emergence of the concept of a "smart human". Smart Human includes citizens, customers, consumers, city dwellers, artists, managers, politicians, entrepreneurs, activists, etc. In short, it is possible to include all profiles of city dwellers in the smart human (Gülseçen, 2020). The participation of citizens living in the city in the smart city plays an integral role and significantly increases the cultures, values, and knowledge that strive for the city (Caragliu et al., 2011). One of the components of the smart city, the "smart human" is the human who uses technology effectively and uses management skills. Cities with "smart human" residents are also referred to in the literature as "Smart Human Cities" or "Human Smart Cities". Cities gain meaning when they become "Human Smart Cities" with participatory governance forms and smart human experiences that create innovation ecosystems where new dynamics are formed (Oliveira & Campolargo, 2015). In smart human cities, the heroes are not technology, but people who are friends with technology. Cities should be living spaces where people living in those cities can enjoy life and their daily work by using all their potential and creativity. Therefore, human smart cities, the new generation of smart cities, are areas that balance technological infrastructure with soft factors such as social participation, citizen empowerment, and people's interaction in physical and virtual environments. The human smart city ecosystem is designed as a combination of physical and digital infrastructure in a systemic relationship with the city's human capital (Depiné et al., 2017).

Kourtit and Nijkamp (2012) state that increasing the socio-economic, ecological, logistic, and competitive performance of cities can be possible by integrating the city's human capital, technological infrastructure capital, and social capital with open network connections and entrepreneurial capital. According to Neirotti et al. (2014), two comprehensive approaches stand out in the Eurocities (2007) European Smart Cities report: Technology-Centric Method (TCM) and Citizen-Centric Method (CCM). The first one states that smart cities' network connections, and thus the use of ICT in every activity in the city, will improve living standards. However, ICT alone cannot contribute to the desired improvements in living standards. There is a need to develop human capital and skill development methods in the city. In the CCM approach, it is emphasized that people and communities can participate more in the information societies formed as a result of the use of information and communication technologies. Data that generates real-time information in the city, enables real-time interventions and contributes to the decision-making processes of public administrators are indispensable technological information sources of the smart city. On the other hand; technology requires investment in human capital through the capacity of talented people. Without human capital, which constitutes the livability of a city, ICT cannot make cities smart. According to Dameri (2017), the human resources dimension of a smart city requires focusing on the development of human infrastructure, creativity, and quality of human resources as well as other human capabilities required to feed the smart city system.

In their work where they create a framework for citizen (smart human) participation in the design of smart cities, Simonofski et al. (2019) divide citizen participation into three categories: citizens as democratic participants, citizens as co-creators, and citizens as users of information and communication technology (Figure 1).

Figure 1

Categories of smart human participation in smart cities (Simonofski et al., 2019)



Smart humans (citizens) can be democratic participants in the city's decision-making process, they can be co-creators to propose better solutions and ideas and reduce the risk of failure early in the process. They can also participate in smart city design as IT users by actively using smart city infrastructure to feel surrounded by technology and participate more easily. Innovative citizen-centered applications; from virtual reality, augmented reality systems, citizen science platforms (Khan & Kiani, 2012) to public digital displays (Du et al., 2017), help citizens feel supported and surrounded by technology and motivated to participate in other applications.

The existence of smart humans is important and necessary for the processes progressing toward becoming a smart society. A smart human is a human who is sensitive to ethical behavior in every aspect of their life, in addition to the ability to use technology effectively. In the last 300 years, the 4th Industrial Revolution was reached in the process extending from Industry 1.0 to Industry 4.0, where digitalization, called the information revolution, was integrated into the industry. Instead of Industry 5.0, Society 5.0, known with definitions such as "Human-Centric Digital Transformation" and "Super Smart Society", was introduced by Japan in 2016 as the "human touch revolution" (George & George, 2020). While the concern in Industry 4.0 was super automation, in the Fifth Industrial Revolution, there was a synergy and understanding of acting together between people and autonomous machines. Digitalization in Society 5.0, unlike the dehumanization movement such as "dark factories" in Industry 4.0, foresees cooperation between machines and people with smart automation, smart systems and devices. It brings together humans and machines to benefit more from human brain power and creativity. Autonomous devices are more predictive, perceptive and knowledgeable about human intentions. In the philosophy of Society 5.0, humans will work without fear of robots and knowing that they can cooperate with them (Nahavandi, 2019). Society 5.0 and the advanced smart societies that can be foreseen in the future will be shaped in line with the extent to which smart humans use information and technology.

Discussion and Conclusion

In the technological context, smart cities can be thought of as factories for the production and processing of large and complex data generated by human mobility and smart devices. Large data

capacities, cosmopolitan city dwellers and tourists as city guests, have great technological and biological diversity. It is possible to say that diversity is an element of richness in smart cities as well as an element that ensures the continuity of biological life. People interact with each other through spoken and written language, gestures, posture and touch. How these interactions can improve the design and development of new ICTs can be the subject of future studies. The development of studies in areas such as the Human-Computer Interaction Field (HCI), Natural Language Processing (NLP) and Speech Technology will facilitate the communication of smart humans with the technological intelligence of the city.

Artificial intelligence technologies that collect and analyze data can respond automatically and quickly to situations in the city, as well as communicate between city actors and infrastructure. A future vision in which widespread technology and software, and the smart human who manages them, will become the key to city management continues to be rapidly formed. The development of smart cities can be possible with the support of open-minded and creative people. Creating user education programs and participation incentive strategies in terms of smart city applications will accelerate the adoption and effective use of smart city applications. For smart cities to be living spaces where artificial intelligence created by technology and biological intelligence created by humans get along well, ethically fulfilling our duties as smart humans who develop technology is the key to today's and tomorrow's prosperous societies.

The aim of this study is to contribute to the field of smart humans. However, the study is a literature review and has limitations. The limitations arise from considering smart humans as technology users in the context of smart cities. Due to the scarcity of existing literature on smart humans, it is valuable in terms of raising awareness and encouraging future research.

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Chapter 18

STEM Education in Innovative Ecosystems

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Abstract

STEM (Science, Technology, Engineering, and Mathematics) education plays a crucial role in fostering innovation, driving economic growth, and solving global challenges. In an innovative ecosystem, STEM education can be the foundation for equipping individuals with the skills needed to thrive in an increasingly technological and interconnected world. Here's how STEM education integrates into innovative ecosystems. The innovative direction of development of the domestic educational system – STEM education – from the standpoint of adaptive processes of its implementation is considered. The changes that occur when using this trend in the practical activities of institutions of general secondary education are highlighted and disclosed. Particular attention is paid to the integration in the educational process of science, technology, engineering and mathematics. STEM competencies are identified for the younger generation and the interrelation of these competences and the principles of implementing STEM education with the principles of adaptive management used in the educational process in the application of innovation. The concept of directed self-organization is revealed. The chapter described features of STEM education in higher education, characterised STEM education in in the context of the adaptive approach, analyse the following principles of adaptive management that used to consciously implement changes in one's own activities. This material presents an example of the prospects for implementing STEM education in Ukraine, legislative acts and regulations, as well as examples of effective application.

Keywords STEM education · principles of adaptive management · integrated learning

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Introduction to STEM

Report from the NSF (National Science Foundation, 2020) outlines a strategic vision for the future of STEM education. It focuses on enhancing STEM learning by promoting equity, broadening participation, and fostering innovation. The report highlights the need for interdisciplinary collaboration, leveraging digital technologies, and addressing societal challenges through STEM fields. Key recommendations include building partnerships between education, industry, and government to develop scalable models that prepare students for future workforce demands in STEM fields.

White's article emphasizes the interdisciplinary nature of STEM (Science, Technology, Engineering, and Mathematics) (White, 2014) education and its importance in cultivating skills like critical thinking and problem-solving. The paper underscores the global shift toward a knowledge-based economy, where STEM literacy is essential. White highlights the role of STEM education in addressing real-world challenges and enhancing competitiveness in the global market. He also stresses the need for integrating STEM early in education to develop future innovators and leaders.

Mirea's paper explores the intersection of STEM (Mirea, 2023) education and artificial intelligence (AI), focusing on the ethical implications of AI integration in educational contexts. The author addresses the need for students to develop both technical and ethical competencies, such as understanding AI biases, data privacy issues, and the societal impacts of AI-driven technologies. Mirea calls for a broader educational framework where STEM students are equipped to navigate the ethical challenges associated with AI, ensuring responsible innovation and usage.

Chovriy's\Pelekh\Rogoza study examines the effective organization of STEM (Chovriy et al., 2024) environments in higher education, focusing on digital tools, immersive technologies (e.g., virtual reality), and collaborative platforms. The paper presents findings from experimental research, showing that STEM-oriented environments enhance critical thinking, practical skills, and professional development among students. The authors recommend the adoption of a variety of digital learning resources and provide practical approaches to implementing STEM-focused curricula and learning spaces.

An article Learning Ecosystems: Building from Theory Toward a Common Evidence Base (Shernoff et al., 2021) discusses the concept of STEM learning ecosystems, which integrate schools, community programs, and informal learning opportunities to create comprehensive STEM education pathways. The authors propose a framework for building evidence-based STEM ecosystems that foster student engagement, inclusion, and collaboration between different learning environments. They emphasize the importance of partnerships between educational institutions, industries, and policymakers to build a sustainable infrastructure for STEM learning and professional development.

Report from ERIC (DeFoor, 2021) examines successful STEM ecosystems and the factors that contribute to their effectiveness. It identifies key elements, such as interdisciplinary curricula, partnerships with industry, and student engagement, that create a robust STEM ecosystem. The report highlights best practices and the need for continuous assessment to ensure equitable access to resources and opportunities. The study also stresses the role of community engagement and collaboration across sectors to support lifelong STEM learning.

This report from the EUA (European University Association, 2021) explores the role of universities in innovation ecosystems, particularly within the context of STEM education. It outlines how universities can contribute to technological and societal advancements through interdisciplinary collaboration and innovation. The report highlights the importance of fostering partnerships between academia, industry, and government to address global challenges. Key areas of focus include digital transformation, sustainability, and STEM education as a driver for economic growth and societal change.

Dr. Tabassum's research investigates the relationship between STEM (Tabassum, 2020) education and creativity among university students. The study finds that STEM education, through its problem-based and project-based learning approaches, significantly enhances students' creative thinking and innovation skills. The paper discusses how STEM curricula encourage students to explore complex problems, think critically, and develop unique solutions. The author advocates for the integration of creativity-focused methodologies in STEM education to cultivate a more innovative and flexible workforce.

Research from Royal Academy of Engineering provides a comprehensive analysis of the UK's STEM (Royal Academy of Engineering, 2022) education landscape, identifying key challenges and opportunities for enhancing STEM learning at all educational levels. It emphasizes the importance of improving STEM skills to meet labor market demands and fostering equity in education. The report discusses the fragmented nature of STEM initiatives and calls for greater coordination across government, industry, and education sectors to build a robust STEM pipeline, focusing on inclusivity and innovation in teaching methodologies.

National Academy of Engineering & National Research Council document highlights strategies for integrating STEM education across K-12 (National Academy of Engineering & National Research Council, 2014) curricula. It explores different models of STEM integration, such as thematic units, project-based learning, and interdisciplinary approaches, aimed at increasing student engagement and achievement in STEM fields. The report identifies the need for systemic changes in school structures, teacher professional development, and curriculum design to effectively integrate STEM in K-12 settings. It also stresses the role of community and industry partnerships in supporting STEM education.

Johannes Kepler University research paper explores the role of universities in fostering regional development, emphasizing their contribution to innovation ecosystems (Thöni, 2022). It examines how universities act as key players in regional transformation through research, education, and collaboration with industries. The report highlights the importance of creating an entrepreneurial university culture, promoting knowledge transfer, and supporting local economic growth by addressing skills shortages. Universities are seen as catalysts for innovation-driven growth, contributing to both local and national competitiveness.

This report by the International Labour Organization (ILO) (International Labour Organization, 2021) discusses the role of skills development in transitioning to a greener economy. It examines the need for green skills in sectors like energy, agriculture, and construction, outlining how upskilling and reskilling initiatives are critical to meet the demands of a low-carbon economy. The report calls for stronger alignment between educational institutions, policymakers, and industries to ensure a just transition, highlighting the global efforts required to foster sustainability in workforce training.

Based on the fact that all the above-mentioned processes require adaptation to innovation in real life, we consider the problem of STEM education in the context of an adaptive approach, which also requires certain didactic actions.

The aim of the chapter is to describe features of STEM education in higher education, to characterise STEM education in in the context of the adaptive approach, to analyse the following principles of adaptive management that used to consciously implement changes in one's own activities.

Features of STEM Education in Higher Education

STEM education in higher education is an important approach to learning that emphasizes the integration of science, technology, engineering, and mathematics. It is actively developing in Ukraine

and around the world, as it provides students with the necessary knowledge and skills to work in technology-oriented fields (Morze, 2018; Holik, 2023).

Collaboration Across Sectors

Education and Industry Partnerships: STEM programs often work closely with industries to align curricula with the needs of the job market. This ensures students gain relevant skills, such as coding, data analytics, robotics, and critical thinking, which are essential for innovation (Kuzmenko, 2017).

Mentorship and Internship Programs: By collaborating with tech companies, research institutions, and start-ups, students gain hands-on experience that connects classroom learning with real-world applications. This promotes innovation by allowing students to contribute to actual projects.

Emphasis on Problem-Solving and Critical Thinking

STEM education is focused on nurturing problem-solving abilities, critical thinking, and creativity. These skills are essential for addressing the complex challenges found in an innovative ecosystem, such as developing sustainable energy solutions, designing advanced healthcare technologies, or creating smarter cities (English, 2023).

Interdisciplinary Learning: Innovative ecosystems thrive when there's interdisciplinary collaboration. STEM education encourages students to combine knowledge from different fields, fostering a more holistic approach to problem-solving.

Innovation in Education Itself

EdTech Integration: Innovative ecosystems often include the integration of new technologies into STEM education, such as AI-powered learning platforms, virtual reality labs, and interactive simulations. These tools not only make learning more engaging but also allow students to experiment with emerging technologies in real-time.

Personalized Learning: STEM programs are increasingly adopting adaptive learning technologies, allowing for customized education experiences based on individual learning styles and pacing. This enhances the learning process, helping students to better grasp complex concepts and innovate in their own ways.

Entrepreneurship and Innovation Mindset

Start-Up Culture in Education: Many innovative ecosystems encourage entrepreneurship through STEM education by providing incubators, accelerators, and funding for student-led projects. This not only promotes innovation but also prepares students to become future leaders and innovators.

Innovation Labs and Makerspaces: Schools and universities in innovative ecosystems often have makerspaces, labs, and collaborative environments where students can design, prototype, and test their inventions. This hands-on experience fosters an entrepreneurial mindset (Felder, 2021).

Global and Local Impact

STEM education drives innovation that impacts both local and global communities. In an innovative ecosystem, STEM projects may focus on solving local issues, such as clean water access, while also contributing to global initiatives like climate change mitigation or sustainable agriculture.

Sustainable Development Goals (SDGs): Many STEM education programs align their projects with global goals, such as the UN's SDGs, encouraging students to innovate in ways that address critical global challenges, including poverty, inequality, and environmental sustainability (Podlesnyi, 2019).

Equity and Inclusion in STEM

Access for Underrepresented Groups: An essential component of building an innovative ecosystem is ensuring equitable access to STEM education for underrepresented groups such as women, minorities, and students from low-income backgrounds. Encouraging diversity in STEM fields brings varied perspectives, leading to more innovative solutions.

Outreach and Community Programs: Many innovative ecosystems promote STEM through community outreach, afterschool programs, and partnerships with non-profit organizations. This increases exposure to STEM fields for younger students and those from diverse backgrounds.

Role of Government and Policy

Governments play a key role in fostering innovative ecosystems through policies that support STEM education, research funding, and infrastructure development. Public-private partnerships often emerge in these ecosystems to further innovation, with governments providing incentives for tech start-ups and educational institutions to collaborate.

STEM Grants and Competitions: Governments, along with international organizations and corporations, often sponsor grants, scholarships, and innovation competitions that encourage STEM students to pursue research and development projects that could have real-world impacts.

Continuous Learning and Workforce Development

Lifelong Learning: In an innovative ecosystem, education doesn't stop with traditional schooling. STEM education is seen as a lifelong journey where individuals continuously upskill and reskill to keep pace with technological advancements. Online courses, boot camps, and corporate training programs play a significant role here.

Workforce Development Programs: Many innovative ecosystems focus on STEM education to prepare the workforce for future technological changes. Programs designed to teach digital literacy, coding, data science, and AI are crucial for workforce competitiveness in a global economy (Haag, 2023).

STEM Education in in the Context of the Adaptive Approach (Ukrainian Analise)

The world around us is changing, we are changing, the content, methods and technologies of human education, its preparation for independent professional activity and the development of readiness to learn throughout life are changing. It is important to shift the emphasis during education to the achievement of a practical result in terms of the formation of skills in using the acquired knowledge to solve various situations in the course of human life (Concept project of STEM education in Ukraine Concept project of STEM education in Ukraine, 2017).

An example of this is the development of a new direction for education regarding the integration of science, technology, engineering and mathematics in the educational process, which is denoted by the abbreviation STEM.

STEM education is a series or sequence of courses or programs of study that prepares students for successful employment, post-secondary education, or both, requiring different and more technically complex skills, including the application of mathematical knowledge and scientific concepts.

The initiation of the development of STEM education in Ukraine belongs to the State University "Institute of Modernization of the Content of Education", where there is a special department that is engaged in the creation, popularization and dissemination of the domestic experience of STEM education (STEM education, 2017).

In March - May, the All-Ukrainian festival "STEM-spring-2018" was announced and held with the aim of creating conditions in Ukraine for the balanced and harmonious formation of science-oriented education, familiarizing the pedagogical public with innovative educational technologies necessary for the implementation of the conceptual foundations of the New Ukrainian School, popularizing engineering - technical professions among students.

The scientific works of such domestic scientists as S. Galat, O. Korshunova, N. Morse, O. Patrikeeva, I. Slipukhina, O. Stryzhak and foreign scientists: Heather Gonzalez, Jeffrey Kuenzi, David Langdon, Keith Nichols are devoted to the problems of STEM education.

However, STEM education has not been considered in the context of an adaptive approach. The purpose of the article is to highlight the practical issues of the interaction of the innovative implementation of STEM education in the educational process and adaptive processes occurring during this implementation.

Materials and Methods (Design/Methodology/Approach)

What are the prospects for the introduction of STEM education in Ukraine? First of all, this is a change in the content of education, starting from kindergartens and ending with higher and postgraduate education. The change should take place on the basis of the integration of various directions as the leading principle of STEM education. Life is multifaceted and requires the development of natural abilities and the formation of life skills in order to choose one's own development trajectory, ensure competitiveness in the labor market, independence in decision-making, the ability to take responsibility, to be in demand in everyday life (STEM-learning, 2024).

The time is not far off when integral professions will appear, which are now it is hard to imagine, they will combine technology, high-tech production and natural sciences. Specialists in bio- and nanotechnologies are expected to be in particular demand.

All this must inevitably activate adaptation processes in a person's life. Therefore, it can be noted that educational activity is not just a subject-subject transfer of knowledge, it is a way of expanding one's own consciousness and changing reality in one's imagination and life. Such a mission of education that will give the result of an active life position of a person. Since a person is affected by a complex of various conditions and influences in life, it is necessary to prepare him for an independent life comprehensively, taking into account the simultaneous influence of nature, science and technology. Educational activity requires a combination of interdisciplinary, practically oriented approaches to the study of natural and mathematical disciplines through the restructuring of educational programs of educational institutions of various levels. Integrated training according to certain topics or real problems is becoming popular. Such training requires new educational technologies for the young generation to acquire key professional, social and personal competencies that condition competitiveness, the ability and readiness to solve complex life tasks, critical thinking, creativity, cognitive flexibility, cooperation, management, implementation of innovative activities, etc. Creativity, organizational skills, the ability to work in a team, emotional intelligence, evaluation and decision-making, the ability to effectively interact, the ability to negotiate, etc. All of the above refers to STEM competencies.

The main principles of implementing STEM education in Ukraine are:

- A personal approach that focuses on taking into account the age, individual characteristics of students, existing interests, inclinations;

- Permanent update of the content (the content of STEM education constantly updated in accordance with the development of science and technology);

– Integrity, which involves the creation of a complete national system for the implementation of STEM education as a component of the unified educational space of Ukraine;

– Civic orientation (STEM education is aimed at increasing the human potential of the state, increasing its competitiveness);

– Productive motivation (formation of productive motivation of participants in the STEM educational process to carry out research and design activities, inventions, participation in various competitions, festivals).

In order to evaluate the results of the implementation of STEM directly in the education system, monitoring should be carried out.

It is common knowledge that interaction in the "teacher-student" system is the first level of management in education. The action of the teacher in relation to the student is a management process. Therefore, we will consider adaptation from the perspective of adaptive management (Yelnikova G.V. (2017)).

To carry out the adaptation of the subject to the environment and the mutual adaptation of the environment to the subject, without which a comfortable life of a person is impossible, it is necessary to rely on certain patterns and use the appropriate principles of adaptive management. Let's note some of them that can be manifested in the process of STEM education.

First of all, this is the concept of directed self-organization, which consists in the implementation by the object of self-direction of its actions to achieve a perceived goal, which is defined as the interaction of multidirectional forces impact on him. It takes place in the process of managerial interaction and covers all its participants at the same time. Each of them, on the basis of dialogic adaptation and awareness of the realism of the goal, creates a model of their activity, chooses its direction in accordance with the laws of their natural development.

From the point of view of synergy, we distinguish 4 stages of directed self-organization: destabilizing, orientational (includes dissipative and cooperative substages), organizational, and effective. Each stage is characterized by certain processes that lead to a specific result, namely changes during innovation, which always occurs in STEM education.

Thus, at the destabilization stage, fluctuation processes of different directions and different force of action take place. This is carried out by various activators: initiators, ideas, orders, orders, schedule of real circumstances. Various actions of activators affect the stable connections of the system. The result is a "shaking" of the system, its complete destabilization.

At the orientation stage, bifurcation processes take place. These processes have two sublevels: dissipative and cooperative. At the dissipative sublevel, there is a breaking of connections and "screening out" of individual components of the system.

At the cooperative sub-level, separate links of joint action begin to be established, the interaction of external and internal influences is determined. There are areas of directed action. The result is a neoplasm, orientation of the system to a specific direction of development.

The organizational stage is characterized by a certain stabilization. At this stage, neoplasms are involved in orderly (directed) actions.

External requirements are adapted to local features and conditions, which in turn acquire features of reality within established limits.

In order to prevent the transition of formative actions into destructive ones, the process implementation is accompanied by ongoing self-analysis and self-correction based on intermediate measurements and evaluation. In this way, directed self-influence is carried out, which is ensured by the transfer of process control powers to the system itself (subject of activity).

At the effective stage, qualitative and quantitative changes are recorded, self-development of the system is realized, which occurs with the help of directed self-influence on achieving its goal within externally established limits.

The result is self-development, set by the agreed goals of the person himself (the subject of activity), society, and the state, taking into account the existing situation.

The following principles of adaptive management are used to consciously implement changes in one's own activities (Yelnikova, 2017):

1) Priority recognition of human development and the determination of the natural path of its implementation (corresponds to the development of STEM competencies, competitiveness). Development is recognised as the driving force behind progress. The natural way of its implementation is crucial, because it is devoid of any degree of coercion. The more coercion, the less progressive development, and vice versa: the less coercion, the more progressive development. Free development gives the best results. There can be no 'pure' free development for a person. He or she is naturally endowed with consciousness, which is also naturally involved in determining the path of development, directing it in the direction chosen by the person. The natural way of human development is to consciously direct it (development) in the direction chosen by man;

2) Management through self-management is carried out by activating a person to manage his activities. At the same time, the processes of external management and self-management are combined. This combination involves the connection of the person himself to self-management already at the initial stage of management through the resonance reaction (corresponds to the formation of the ability and readiness to solve complex life tasks). In other words, indirectness in adaptive management is provided by the person himself through self-management. A person's 'inclusion' in this process occurs through a resonance reaction, which indicates the emergence of interest and the person's ability to effectively perform the task;

3) Resonance emphasizes the need to activate the internal needs of a person. The system is capable of progressive development only in an active state. The active state of a person is the readiness to perform those actions (those tasks) that will contribute to the development of his abilities and inclinations or realize his own interests. Therefore, not every influence on a person from the outside leads him to motivated actions, but only the one that corresponds to the direction of development of the person himself. Such influence causes a response in the form of readiness for action, and the stimulus that exerted this influence is determined by the activator, because it brings a person into an active state. All together constitute the phenomenon of resonance. Resonance can not only ensure the further development of already active abilities and inclinations, but also awaken them "dormant" features of a person at any age (corresponds to the development of critical thinking, creativity, cognitive flexibility). Resonance makes it possible to take into account a person's self-interest in management. Helvetius compared the role of self-interest in society to the law of gravity. In the long run, society still wins;

4) Adaptability involves mutual adaptation of the goals of managers and executors (subjects of management), coordination and mutual adjustment of requirements and expectations of all participants in the management process. Dialogic agreement ensures the convergence of different points

of view, which helps to achieve mutual understanding and prevents the occurrence of conflicts (implements the ability to cooperate, manage, work in a team, and negotiate). An example of such an organisation of interaction is the combination of centralisation and decentralisation of management in Japanese firms. This is a special style of management that involves coordination and coordination of actions of all hierarchical levels, development and adoption of decisions only after detailed discussion and approval by executives;

5) Motivation consists in the formation of such a basis that makes it possible to work without external levers of coercion. Work goes from externally controlled to motivated, which is performed by good will. This removes the resistance that occurs with any degree of coercion, the freed forces are directed to improving the quality of work (implements the motivational component of the introduction of STEM education, the principle of "productive motivation"). In general management, the Finnish performance management system is known for its non-coercive nature. It is a system of management and development that achieves goals that are agreed upon and defined by all members of the organisation. It is based on the 'contribution - result' model.

Various types of incentives are used to create a motivational framework. Motivation is based on basic and psychological human needs. Motivation is a compulsion to act to achieve a goal (satisfy needs). The incentive mechanism can be money or the creation of conditions to meet the needs for communication, recognition, self-affirmation, etc.;

6) Constant improvement of competence implies that the performance of any task requires expanding the range of issues that a person possesses. Constant improvement of competence satisfies the need for recognition and self-affirmation, which stimulates human activity (corresponds to the principle of STEM education implementation, permanent updating of content). This can be achieved by delegating responsibility to lower levels of management, periodically changing functions, mastering new technologies and equipment, etc. For example, many Japanese firms do not have 'clear job descriptions that define the scope of employees' responsibilities, based on the premise that the content of employees' activities may change, and they must be able to perform any work within their competence';

7) Directed self-organization is based on a more complete use of intellectual and moral-psychological management reserves. This is achieved by transferring the authority to direct the development of a person to the person himself (implements the organizational abilities of the subject activities and personal approach in STEM education). For example, the development of the management process in American firms is associated with the use of the concept of humanisation of labour. This allows enriching individual work by giving independence to a person, expanding the range of issues to be solved, creating autonomous and semi-autonomous groups, etc. When using the principle of directed self-organisation, the management subsystem sets general boundaries or formulates requirements for development (functioning). The adaptation of these requirements to local conditions is carried out by the person (organisation) itself, and it chooses the ways, methods, and forms of performing its actions to achieve the tasks. This principle more fully reveals and clarifies the principle of management through self-management.;

8) Cooperation involves the organization of joint actions in the vertical and horizontal layers of the management system to achieve a common goal (implements the integration of activities through the permanent integration of the content of STEM education). This principle, for example, is laid down in the 'Hartzburg model', which was developed in the 1960s at the Academy of Management Personnel under the leadership of Reinhard Hahn (Germany). In essence, it presents a mechanism of co-operative management, when the right of responsibility for decision-making and implementation is given to employees who are most competent in specific issues to be resolved. The same principle underlies

participatory management, when staff is involved in decision-making, which expands the degree of employee participation in the management process.;

9) Monitoring. This principle emphasizes the need for ongoing self-analysis and self-direction of the process to a given result on the part of executors and external periodic analysis to track the dynamics of changes on the part of managers (implements monitoring support for STEM education). Monitoring is based on an input-output model. The manager takes measurements at the entrance and exit. The process is monitored by the performer. Self-regulation is carried out using self-reflection (binary feedback to oneself) and according to predefined criteria, evaluation standards, etc. For self-regulation, a special standard is developed, a benchmark - a qualimetric model (submodel) of activity. In developing this model, the actions of managers and executives in the vertical and horizontal layers of the management system are co-operated. This makes it possible to realise the realism of the task and one's own influence on the management process, which helps to increase motivation and a sense of personal significance. The very fact of delegating the authority to control the process increases a person's responsibility for the quality of work;

10) Qualimetry - consists in quantitative measurement of the quality of work using conditional points. The tools for educational monitoring are special factor-criterion models (performs evaluations and helps in decision-making). They consist of factors that are conventionally taken to be the areas of activity as factors affecting its quality. The list of components of each area is conditionally accepted as criteria as a 'measure' of the requirements for these areas. For each factor and each criterion, the value of its weight among all factors or criteria is calculated. The weighting value shows the priority of the actor's action and is called the 'activity vector'. If the weighting is calculated based on regulatory requirements, it is called a regulatory activity vector. If the weight is calculated based on the results of a survey of teachers of a particular team and reflects their priorities, it is called a real activity vector;

11) Joint forecasting of further development based on the analysis of the result (accompanying the implementation of innovative activities, the formation of creativity). The degree of achievement of a given result is determined, certain parameters are measured, and quality indicators are evaluated. A conclusion is drawn on whether the desired changes have been made and whether expectations have been met or not. Based on the information received, a joint effort (supervisor - subordinate or a separate group of performers) determines the further path of a person, group, organisation, etc. An important distinction of adaptive management is the stage of forecasting, rather than identifying shortcomings and drawing up an action plan to address them. Looking forward is always about progress;

12) Openness in adaptive management involves, firstly, the openness of internal relations due to the removal of psychological protection from all participants in the management process. This is a mandatory condition for cooperation of actions. Only in a state of openness is mutual enrichment and the naturalness of partnership relations possible. Secondly, this principle emphasizes the openness of external relations. For example, the publication of the results of the certification of teaching staff, students, educational institutions, etc. This contributes to the development of public opinion, which becomes a regulator of the activity of a person, organization, etc. (contributes to civic orientation, the integrity of the implementation of STEM education, the formation of emotional intelligence). In his work 'Applied General Systems Theory', Geeg J. Geeg emphasises that it is necessary to find principles and methods that will contribute to social progress and development of society. In our opinion, adaptive management meets this challenge. It is based on the idea of directed self-organisation. This idea emphasises the inclusion in the natural processes of human development of those actions that establish a dynamic balance of the needs of the individual, society and the state. It is not about imposing these actions from the outside, but about their conscious choice on the basis of dialogical adaptation through the joint development of appropriate models of activity (co-evolutionary path).

Conclusion

The technology of adaptive management is associated with various ways, methods and means of its implementation and is implemented with the help of educational monitoring.

STEM education and the essence of adaptive management are very close in terms of purpose and specific tasks. It can be argued that adaptation completely accompanies stem-education, because adaptive management always arises arbitrarily in the process of changes, coordinating multidirectional influences on the subject of activity.

STEM education is a creative space for a child's outlook, where he not only prepares for adult life, but also fully realizes his needs. Therefore, all activities related to the implementation of STEM education are structured in such a way as to contribute to the formation of an individual as a creator and designer of one's own life, based on the idea of a conscious choice of a personal life path. And the technological basis of this implementation consciously (or unconsciously) is an adaptive approach and principles of adaptive management.

STEM education is a cornerstone of innovative ecosystems, driving creativity, entrepreneurship, and problem-solving on a global scale. By fostering partnerships between education, industry, government, and communities, STEM programs can help nurture the next generation of innovators who will solve some of the world's most pressing challenges.

The chapter described features of STEM education in higher education, it was characterized STEM education in in the context of the adaptive approach and analyzed the following principles of adaptive management that used to consciously implement changes in one's own activities.

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Chapter 19

Through the Looking Glass: Is the City Smart or the Human Smart?

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Abstract

This study reviews the literature on "Smart City" and its sub-component "Smart Human," focusing on human behavior in international studies conducted outside Turkey. The aim is to examine and compare selected publications, offering new perspectives to the field. Two case studies are analyzed: the "Smart Human Kit" project in Amsterdam, which evaluates participants' roles in smart city transformations through republican and cybernetic citizenship frameworks, and the "Virtual Mobility" project, which assesses virtual solutions for student exchange and internship practices. These studies explore critical issues and propose improvements to foster smart human characteristics. This research contributes to the literature by emphasizing the significance of human-centric approaches in urban digital transformation.

Keywords Smart city · smart human · smart citizen

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Introduction/Background

Systems are always developed to serve human needs. However, do all systems fulfill this purpose? To what extent do the systems in question serve human beings, and how effectively do they meet human needs?

Concepts like "Industry 5.0," "Life 3.0," and "Human 2.0," which emerged during the industrial revolution, represent efforts to align digital transformation with sustainability. These ideas are increasingly reflected in smart city applications, where information and communication technologies (ICT) offer rational solutions to urban challenges in social, environmental, and public domains (Erdoğan, 2020). Developments in data mining, social media, and software engineering have also driven the transformation from traditional e-governance to advanced smart city models (Akgül, 2013).

Smart cities employ technologies such as the Internet of Things (IoT), cloud computing, big data, artificial intelligence (AI), and blockchain to address challenges in areas like transportation, energy, healthcare, and social life. Data collected from citizens-the core of city life-are processed to enhance urban living and provide people-oriented solutions (Hassan et al., 2021; Jebaraj et al., 2023; Köseoğlu et al., 2018; Kyriazopoulou, 2015; Law & Lynch, 2019; Şen, 2020; Ulusoy, 2017).

The complexity of smart cities necessitates a multidimensional evaluation approach, as their development and functioning involve diverse processes. The European Parliament's framework for smart cities identifies six key components: Smart Economy, Smart People, Smart Governance, Smart Living, Smart Mobility, and Smart Environment (Ferrara, 2015; Gülseçen, 2021). Each component converges on a human-centric focus, making the "Smart Human" the cornerstone of any smart city.

Evaluations of smart city applications generally focus on metrics like the number of citizens reached, usage rates, and success relative to predefined targets. However, human-centric assessments remain relatively rare. For instance, Bilici and Babahanoğlu (2018) evaluated smart city applications in Turkey, concluding that they are in their infancy compared to global examples and often emphasize technology at the expense of other critical dimensions.

Similarly, Çetin and Çiftçi (2019) observed that international studies often prioritize components such as "Smart Environment," "Smart Transportation," "Smart Governance," and "Smart Economy." They argue for a greater focus on "Smart People" and "Smart Life," emphasizing that using rapidly evolving innovations in information and communication technologies as a foundation could lead to a more holistic and successful approach to smart city applications.

Human-centered studies in this field predominantly analyze observable behaviors and simulate their interactions with urban systems. This study highlights examples of such human-oriented research, focusing on the "Smart People" component of smart cities. By sharing international case studies, it seeks to inspire further research and contribute to advancing the field of human-focused smart city development.

Materials and Methods (Design/Methodology/Approach)

This study employs a traditional review of international studies conducted outside Turkey. The traditional review method synthesizes findings, results, and evaluations from two or more studies on a specific topic. While traditional reviews are considered at the base of the evidence pyramid, they provide valuable expert perspectives and contribute to the literature (Karaçam, 2013).

The review was conducted using academic search engines such as Google Scholar (academics.google.com), PubMed, and others (2022). Keywords included "smart city," "smart human," "smart citizenship," and "smart cities." Relevant studies focusing on human behavior and human-

oriented smart city applications were selected for analysis. The review highlights applications that simulate human behaviors within smart city frameworks, compiling examples from key works (Caldirola et al., 2014; Zandbergen & Uitermark, 2020).

In Search of Smart Citizen: Republican and Cybernetic Citizenship in the Smart City

Zandbergen and Uitermark's study in Amsterdam centers on a project encouraging citizens to collect and share air quality data. Drawing on ethnographic research, the project critiques the vertical, top-down approach to smart city policies. It explores the interplay between republican and cybernetic citizenship, demonstrating how individuals negotiate urban life through data and sensing technologies. Republican citizenship emphasizes collective sovereignty, where citizens engage in governance and decision-making processes. In contrast, cybernetic citizenship highlights individualized participation, where people interact with information systems based on personal preferences and needs.

This dual citizenship framework aligns with the goals of smart cities, particularly in advancing "Smart People," "Smart Governance," and "Smart Economy." Citizens who demonstrate high competencies in these areas and are more adaptable to technological innovations are characterized as Cybernetic Citizens. The study illustrates how both republican and cybernetic citizenship contribute to visions of urban life that appeal to diverse stakeholders.

The Waag Society, a bureau for creative technology and social innovation in Amsterdam, collaborated with the public-private Amsterdam Smart City network to distribute 75 self-assembly measurement kits. The kits, called Smart Human Kits, include a mini-computer and sensors that measure air pollutants such as carbon monoxide (CO) and nitrogen dioxide (NO_2), along with air temperature and sound levels. An online platform aggregates the data and displays it on a map. The project employs the term "Smart Citizenship" to describe proactive, tech-savvy participation. Frank Kresin, a Waag Society project leader, describes Smart Citizenship as involving "engaged and enlightened individuals who connect, share resources, and use technology to make informed decisions" (Henriquez, 2015; Hill, 2013).

Figure 1

Smart Human Kit

Despite the project's innovative approach, the Smart Citizen Kits were found to be insufficiently accurate for air quality measurements. The final project meeting revealed no clear correlation between

the data collected and actual air pollution levels. Waag Society (2014) acknowledged the kits' limitations but noted that participants found the process engaging. While 80% of survey respondents indicated partial satisfaction with the project, many expressed interest in participating in future studies. These mixed evaluations reflect differing types of citizenship, with republican citizens focusing on collective decision-making and cybernetic citizens valuing individualized interaction with data.

The project highlights the evolving nature of citizenship in digital urban environments. Republican ideals empower participants to address public issues collaboratively, while cybernetic frameworks emphasize individual agency in navigating data-driven systems. Together, these models illustrate how data collection and participation can enhance governance and foster new articulations of urban citizenship.

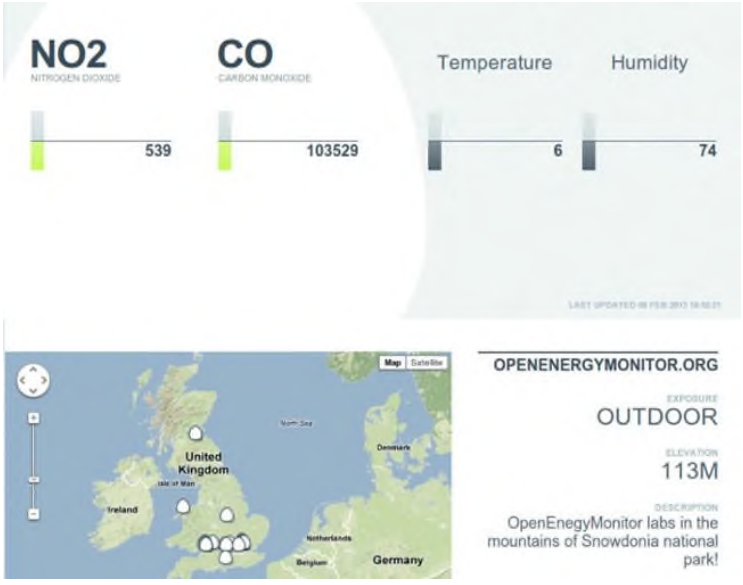
Figure 2
Air Quality Egg

The Smart Citizen Kit Project demonstrates how data infrastructures shape evolving forms of citizenship in smart cities. Based on ethnographic research conducted between 2011 and 2018, the project extends earlier efforts such as the Air Quality Egg Project, which introduced low-cost "Do It Yourself" (DIY) digital technologies for environmental monitoring. These DIY processes exemplify cybernetic citizenship, fostering citizen awareness, capacity building, and community empowerment.

Participants used the data they collected to engage in discussions about air quality, integrating elements of republican citizenship by participating actively in administrative processes. Unlike its predecessor, the Smart Citizen Kit Project was more explicitly linked to Amsterdam's local smart city initiatives, reflecting a stronger alignment with governance priorities (Kickstarter, 2012; Zandbergen, 2017).

Figure 3
Air Quality Egg Map

Figure 4
Air Quality Egg Info



While the kits did not produce highly accurate data, participants were encouraged to view themselves as data authorities, addressing gaps in government-collected information. This approach illustrates the republican ideal of empowering citizens to collaboratively address public issues. Additionally, the project highlighted the value of cybernetic environments, where real-time, sensor-driven data creates new opportunities for personalized interaction with urban systems.

The concept of cybernetic citizenship was introduced through futuristic narratives of seamless integration with sensors, data, and artificial intelligence. This framework emphasizes an individualized approach to data interpretation, where collective data fails to establish a shared societal language but

instead creates an emotional, adaptive environment tailored to personal needs. Participants described this process as offering "insights through data," accessing and evaluating sensor-collected information based on their preferences.

The Smart Citizen Kit Project underscores the potential of smart citizenship as a paradoxical and flexible construct. While participants enjoyed real-time, personalized interactions with the kits, the project's final report suggested future improvements through calibration and enhanced sensor accuracy. Project leader Saskia Müller emphasized that the initiative, while impactful, could have been more successful if it had encouraged broader data collection efforts (Amin, 2015; Thrift, 2014).

Smart Mobility and Smart Learning for a New Citizenship

Caldirola et al. (2014) explore the concept of new citizenship in their study, "Smart Mobility and Smart Learning for a New Citizenship." The research proposes sustainable solutions through various European projects, focusing on mobility for education and work experience, as well as leveraging social networking technologies to address globalization challenges. A key aspect of the study is virtual mobility, presented as an alternative to physical mobility. For many students, financial, social, or logistical barriers make international travel infeasible. The study emphasizes providing guidance for students participating in Erasmus and other exchange programs, offering support before, during, and after their involvement.

Virtual mobility is discussed in two primary contexts: academic learning and company-based internships.

Defining Virtual Mobility

Open Education Europa (formerly learningeuropa.info) defines virtual mobility as "the use of information and communication technologies to provide the same benefits to a student as physical mobility, without the need to travel" (Open Education Europa, 2013). Similarly, "Being Mobile" defines it as "a learning method in which students use information and communication technologies to create collaborative learning environments, enabling them to work with individuals from different countries to enhance intercultural understanding and knowledge transfer" (Bijnens et al., 2006).

Through the application TeaCamp, students can take courses from host universities in other countries, gaining academic credits and subject-specific skills. The platform also allows access to different cultures, languages, education systems, and technological competencies without requiring physical travel. Features of the Being Mobile project include collaboration among students from diverse countries, international teaching teams, multicultural exchange, shared curricula, and innovative technological solutions. The project also incorporates virtual internships and training as part of its approach to enhancing mobility opportunities.

Stakeholders and Their Roles

Virtual mobility programs are shaped by three main stakeholders: students, the university of origin, and target companies.

Students: International internships enable students to tackle problems requiring logical, technical, and analytical competencies, enhancing their employability. The focus shifts from foreign education to CV development, highlighting the importance of internationalization in career advancement.

University of Origin: Universities must prioritize the quality of internships by offering ongoing counseling, peer feedback, and monitoring, ensuring students gain meaningful experiences.

Target Companies: Companies benefit from hiring candidates with international experience, who are often more adaptable and independent. However, international internships are not widely available, necessitating strategies to address these gaps.

Critical points for effective internships include focusing on local and national markets, fostering strong communication between stakeholders, and ensuring accurate follow-up on tasks. Aligning the goals of students, universities, and companies is essential to maximize the benefits of these programs. To this end, virtual mobility offers a cost-effective, flexible alternative to traditional methods, particularly in specialized subject areas (Bijnens et al., 2006; Straub, 2010).

Virtual Mobility Projects and Barriers

This study primarily analyzes four virtual mobility projects: TeaCamp - Teacher Virtual Campus, EU-VIP - Corporate-University Virtual Placements, PROVIP - Virtual Placement, and I2Agora - Internship Agora. Additionally, other projects related to virtual mobility such as E-MOVE, PICS, More VM, MOVINTER, NetACTIVEi AIESADEADTU, and others are discussed. The study addresses the barriers and challenges identified in these academic projects, focusing on pedagogical, technological, organizational, institutional, and cultural issues.

Pedagogical Issues

Pedagogical barriers include challenges such as the prerequisites for students, the human factor, and the integration of intercultural exchange as a regular method. The study suggests that students should be proficient in the use of information and communication tools, including both synchronous and asynchronous communication. Additionally, students should possess strong motivation, self-regulation, self-management skills, and metacognitive abilities. To address these issues, it is proposed that educators focus on ensuring communication occurs similarly to face-to-face interaction. To facilitate intercultural exchange, it is recommended that students be encouraged to think critically about key concepts and differences through scenario-based learning.

Organizational Issues

The organizational aspect highlights the issue of "Participation," where the first commitment to the process is crucial. Clear rules for the virtual process and the role of universities in setting these guidelines are essential. In terms of internship models, projects based on long-term cooperation are seen as more effective. Identifying problems in pilot studies and establishing clear frameworks and communication protocols can help overcome challenges related to methodology and tasks. It is also emphasized that the tasks involved should be achievable, challenging, and suitable for virtual environments.

Technological and Institutional Issues

Technological tools should serve as support, not obstacles. These tools need to be user-friendly and accessible to all stakeholders, and it is suggested that technologies be piloted through preliminary applications. The study also identifies institutional challenges, particularly in the relationship between universities and the business community. This can be addressed through personal meetings and mutual understanding between stakeholders.

Stakeholder Cooperation

The successful implementation of virtual mobility programs requires effective communication and cooperation among all stakeholders: students, universities of origin, and target companies. Universities and companies should collaborate in developing curricula and programs that meet student expectations while fulfilling institutional goals. Additionally, international cooperation requires preparatory work, especially in harmonizing language and processes across borders. Mechanisms to ensure the accreditation of virtual mobility practices are essential for making these programs more effective.

Results and Discussion (Findings)

The research compiles two different applications in foreign literature that are human-oriented within the framework of the concept of intelligent human. It is important for the research that it is research conducted in a human-centered manner. It is noteworthy that they are different from the performance-oriented studies in the literature.

This study explores two human-centered applications within the smart human concept, both drawn from international literature. These studies are noteworthy for their human-oriented focus, which contrasts with the performance-oriented research often found in the field.

Smart Human Kit Project

Although the technology used in the Smart Human Kit Project was not sufficiently sensitive to measure air quality accurately, the project revealed important insights for participants. It enabled participants to engage with smart city components through the smart human concept, fostering self-efficacy as they assembled and operated the kits. This experience contributed to individual awareness, a key characteristic of smart humans.

Through data collection, participants became "data authorities" within the smart city. Their ability to gather, access, and evaluate data empowered them to engage in governance processes, reflecting republican citizenship. Additionally, the use of real-time data provided opportunities to observe the role of cybernetic citizenship, emphasizing individual interaction with information and communication technologies.

Participants gained valuable experience in both individual and collective decision-making processes, enhancing their self-confidence in contributing to governance and decision-making within the smart city framework.

Virtual Mobility Project

The Virtual Mobility Project evaluates student exchange programs, focusing on both academic coursework and internship processes. The study aims to eliminate barriers that prevent students from accessing such opportunities due to social, financial, or physical limitations. Virtual mobility offers a practical solution to these challenges, making use of information and communication technologies to provide inclusive educational and internship experiences.

The project emphasizes three key stakeholders-students, universities, and companies. Effective communication and collaboration among these groups are vital for the success of virtual mobility applications. Universities and companies should prioritize shared curricula, expectations, and competencies of lecturers to ensure a smooth virtual mobility experience.

Common Barriers and Solutions

Common barriers identified across both virtual mobility models include language proficiency, workload preventing engagement with social aspects, and challenges with tools and methodologies. Key solutions include creating a common language, aligning curricula across institutions, and providing continuous support for technology infrastructure. Work is ongoing to address these critical points and to develop common platforms that eliminate obstacles to successful virtual mobility programs.

Conclusion

The studies discussed in this review are directly human-oriented, focusing on human behavior within the context of smart human thinking. By highlighting human-centered approaches, these studies contribute to the broader understanding of how people engage with the digital transformation process.

Increasing research that concretizes and disseminates smart human thought will aid individuals and institutions in adapting to the evolving digital landscape. This study aims to contribute to the field by promoting human-centered studies, fostering the development of smart cities that prioritize citizens' participation and well-being.

In conclusion, the studies discussed in the review are directly human-oriented and conducted within the context of human behavior, which contributes to the awareness of smart human thinking. The proliferation of such studies, which encompass concretizations for the advancement and propagation of intelligent human thought, will prove illuminating for individuals striving to adapt to the digital transformation process. In this regard, the objective is to make a contribution to the field by increasing the number of studies in the literature that are oriented towards the humanities.

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Chapter 20

Topic Modeling: Understanding and Interpreting Information for a Human-Centered Future

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Abstract

Topic modeling (TM) stands as a fundamental unsupervised machine learning technique employed for discovering latent thematic structures within vast amounts of unstructured text data and extracting meaningful information in today's data-intensive world. This book chapter provides a comprehensive overview of TM, detailing its definition, fundamental principles, and historical evolution—ranging from early algebraic approaches such as Latent Semantic Analysis (LSA) and probabilistic models like Latent Dirichlet Allocation (LDA), to contemporary embedding-based techniques. Additionally, the underlying mechanisms and respective merits and limitations of foundational TM algorithms (e.g., LSA, NMF, LDA, BERTopic), categorized into three primary types—algebraic, probabilistic, and embedding-based—are reviewed. Underscoring that TM extends beyond a purely theoretical construct, the chapter illustrates its potential to facilitate sense-making and address practical challenges through concrete applications in diverse domains, including the social sciences, business, health, education, media analysis, Natural Language Processing, and software engineering. Ultimately, this chapter positions TM as a powerful and versatile methodology for deriving in-depth understanding from text-based data and translating these insights into tangible value across diverse disciplines. Its capacity for facilitating the comprehension and interpretation of information establishes its significant place within the contemporary data analysis toolkit.

Keywords Topic modeling · human-centered future · LDA · text analysis · embedding-based models

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What is Topic Modeling?

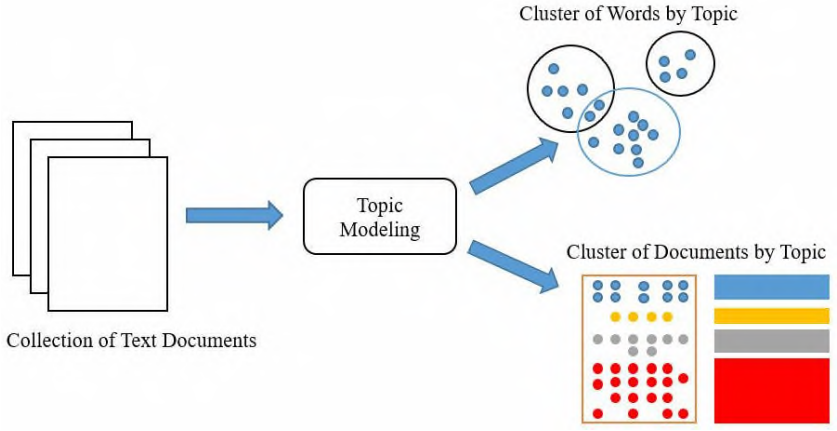
Topic modeling (TM) has emerged as a pivotal tool for extracting meaningful insights from large text collections within our contemporary data-centric world. Fundamentally, this unsupervised machine learning technique operates by focusing on the co-occurrence patterns of words within documents. Its objective is to automatically identify the underlying, directly unobservable "topics" or themes —essentially, distinct clusters of words—present in the text (Blei, 2012). The foundational principle underlying TM rests upon the assumption that each document comprises a mixture of multiple topics, and every topic, in turn, is characterized by a particular distribution over words (Voskergian et al., 2024). This enables documents to be automatically associated with relevant topics, thereby providing a foundation for various applications such as information retrieval (IR), document classification, and content recommendation. These discovered topics represent the thematic essence of the documents at a high level of abstraction, facilitating the organization, summarization, and comprehension of large, unstructured data corpora (Lamba & Madhusudhan, 2022). Consequently, TM affords researchers and practitioners the capability to analyze the core themes within complex textual data in a more systematic and effective manner (Abdelrazek et al., 2023; Kherwa & Bansal, 2018).

In terms of its operational mechanism (Figure 1), TM analyzes a document collection to detect statistical patterns of words and phrases, automatically generating clusters of words (topics) that best represent the collection semantically (Lakshminarayana Reddy & Shoba Bindu, 2023). This automated text processing capability is particularly valuable for organizations that generate or handle large volumes of textual data daily, such as social media posts, emails, or customer feedback, as the manual analysis of such data is considerably laborious and time-consuming. TM accelerates the analysis workflow by automatically extracting the principal topics within documents and their associated keywords. Furthermore, in contrast to traditional methods reliant on simple keyword counts, it provides more in-depth and interpretable inferences at the topic level.

This methodology has established itself as a fundamental technique in related domains such as text classification and sentiment analysis, and its importance continues to grow owing to its interdisciplinary applicability across a broad spectrum, from data analysis to bioinformatics (Hankar et al., 2025).

Figure 1

Graphical representation map for Topic Modeling



Source: Created by the author, inspired by Lakshminarayana Reddy & Shoba Bindu 2023

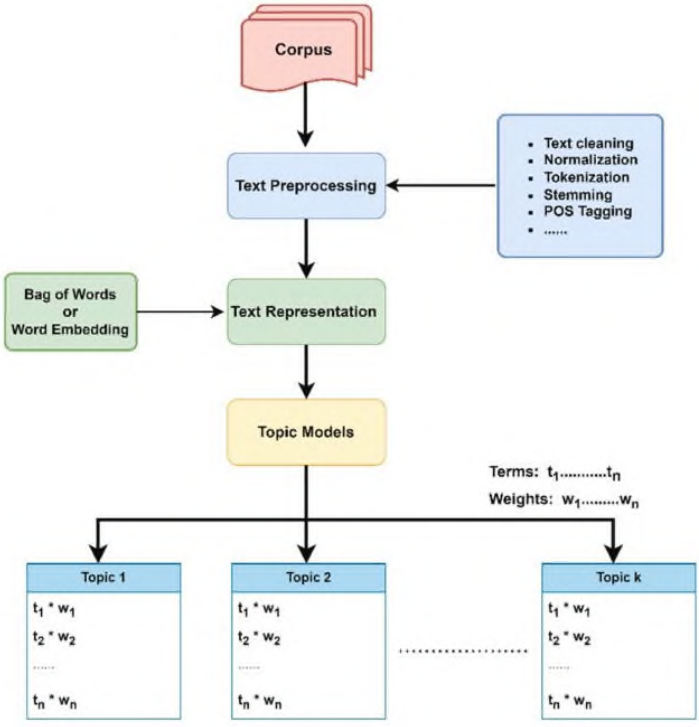
The benefits afforded by TM find tangible applications in diverse fields including IR, recommender systems, social network analysis, bioinformatics, and Natural Language Processing (NLP). In the domain

of IR, for instance, TM enhances the relevance of search results by elucidating the underlying themes within texts, thereby facilitating access to more contextually appropriate information aligned with user intent (Dobsa & Dalbelo-Basic, 2004; Hankar et al., 2025). It has been demonstrated that TM techniques, such as Latent Dirichlet Allocation (LDA), can significantly improve the performance of IR systems compared to traditional methods (Albalawi et al., 2020; Park & Ramamohanarao, 2009; Wu, 2015). By mapping documents to their underlying topics, these models contribute to a better understanding of user queries and subsequently enhance the quality of search results (Chen et al., 2012; Mimno & McCallum, 2007).

Similarly, within the context of recommender systems, TM can be effectively employed to model user interests and preferences based on their past interaction data. This capability allows systems to deliver more personalized and relevant content, product, or service recommendations to individual users, thereby enhancing user experience and satisfaction (Albalawi et al., 2020; Valdez et al., 2021). By analyzing user behavior patterns and topic-based preferences, businesses can optimize their market strategies and strengthen customer engagement (Papadia et al., 2022; Xing & Allan, 2009). The versatility of TM is further evident in fields such as social media analytics, where it is utilized to understand dominant narratives, public opinion trends, sentiment dynamics, and the evolution of discourse within various communities by analyzing vast amounts of user-generated text data (Blei & Lafferty, 2006; Chakkarwar & Tamane, 2023). With its potential for real-time analysis, TM solidifies its interdisciplinary significance as an indispensable tool for both academic research and industrial applications (Hansson, 2021; Rawat et al., 2022; Valdez et al., 2021).

Figure 2

General process of topic modeling



Source: Hankar et al. 2025

The TM process, as outlined in Figure 2 (Hankar et al., 2025), typically encompasses several fundamental steps: data collection, text preprocessing, model selection, and evaluation of the obtained results. Text preprocessing stages, particularly tokenization (segmenting text into words or units), the removal of stop words (common, uninformative words), and stemming/lemmatization (reducing words to their root or base form), are critically important for enhancing model performance and the quality of the outcomes. In the model selection phase, the choice among different algorithms-such as LDA, Non-negative Matrix Factorization (NMF), or Correlated Topic Models (CTM)-largely depends on the specific characteristics of the data being analyzed and the objectives of the research question. However, a crucial consideration for researchers at this juncture, as noted by Egger and Yu (2022) in their work, is that the performance of various topic models can exhibit variability depending on the nature of the dataset; consequently, the selected algorithm may not always be equally effective.

In summary, as delineated in this section, TM is a powerful computational technique designed to discover the thematic structures inherent in unstructured text data. By treating documents as mixtures of topics and topics as probabilistic distributions over words, its core principle provides a systematic framework for making sense of, organizing, and extracting valuable information from large text collections. Its broad range of applications-spanning from enhancing IR and analyzing social trends to delivering personalized recommendations and synthesizing scientific literature-underscores the growing importance and versatility of TM for both academic research and practical applications. This technique holds a central place among modern text analysis methodologies due to its capacity to transform raw text data into structured and interpretable information.

Historical Development of Topic Modeling

The historical origins of TM trace back to the latter quarter of the 20th century, driven by the increasing pursuit of methods to extract latent semantic structures from text data. One of the pioneering approaches in this domain was Latent Semantic Analysis (LSA), first presented at a conference in 1988 (Dumais et al., 1988) and subsequently established in the literature through an expanded publication titled 'Indexing by LSA' in 1990 (Deerwester et al., 1990). LSA fundamentally aimed to represent the relationships between words and documents within a lower-dimensional 'semantic space' by applying Singular Value Decomposition (SVD) to the term-document matrix, thereby enabling the quantitative modeling of latent semantic relationships (Deerwester et al., 1990). However, the mathematical approach underlying LSA also entailed significant limitations, including the model's difficulty in fully capturing linguistic nuances such as polysemy or synonymy, the challenge that interpreting the resulting dimensions was not always straightforward, and practical difficulties in generalizing the model to new, unseen documents (Rani & Kumar, 2021; Yu & Xiang, 2023).

With the aim of overcoming these aforementioned limitations of LSA, Probabilistic Latent Semantic Analysis (pLSA) was proposed by Hofmann in 1999 (Hofmann, 1999). pLSA introduced a probabilistic framework to TM, offering a more flexible structure. The core idea behind pLSA is predicated on the assumption that observed document-word pairs arise from a mixture of underlying latent topics within documents, and each topic is, in turn, represented by a specific distribution over words (Hofmann, 1999; Zong et al., 2021). However, the pLSA model encountered certain difficulties in effectively generalizing the learned structure to new, previously unseen documents, thereby limiting its flexibility in practical applications (Wang & Zhai, 2017).

A true watershed moment in the field of TM occurred with the development of LDA by Blei, Ng, and Jordan in 2003 (Blei et al., 2003). LDA is capable of modeling both the distribution of topics within documents and the distribution of words within topics by utilizing Dirichlet prior distributions. This feature significantly enhanced LDA's generalization ability, addressing the shortcomings of earlier

methods. Owing to its solid theoretical foundation and improved generalization capability, LDA quickly became established as the standard reference model in the field, forming the basis for numerous subsequent studies (Yu & Xiang, 2023).

Beginning around 2013, the rapid proliferation of deep learning, and particularly word embedding techniques within the field of NLP, began to profoundly influence TM approaches. During this period, neural network-based topic models emerged, leveraging dense vector representations (embeddings) that more effectively capture the semantic content and contextual relationships between words and texts, in contrast to traditional probabilistic models often reliant on word counts from document-term matrices (Zhao et al., 2021). These embedding techniques afford a more nuanced understanding of language, enabling models to represent more complex semantic structures (Cao et al., 2015; Shen et al., 2018). Such neural approaches, and others like them, have presented alternatives to conventional methods-particularly concerning challenges like handling large vocabularies, better modeling of context, and sometimes generating more coherent topics (Jin et al., 2018; Kaur et al., 2023)-thereby opening new avenues for research and development in the field (Asgari-Chenaghlu et al., 2020; Jin et al., 2018; Kaur et al., 2023).

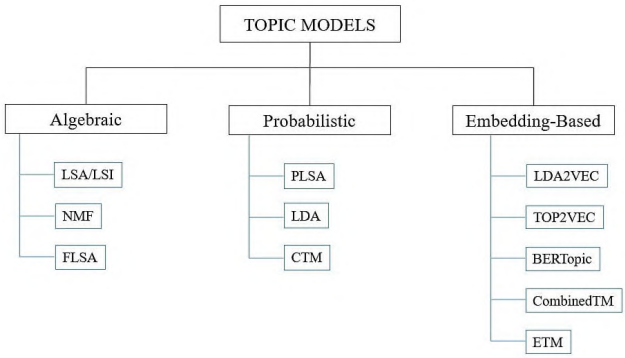
Viewed through its developmental trajectory, the field of TM exhibits a clear progression from foundational statistical methods towards probabilistic models, and subsequently towards deep learning-based approaches. The process, initiated with fundamental techniques like LSA in the late 20th century, gained a new dimension with the probabilistic perspective introduced by pLSA in the late 1990s. The field experienced significant momentum with the advent of LDA in the early 2000s, which is understood to have been widely accepted as the standard approach for a considerable period. From 2013 onwards, however, the increasing influence of deep learning and word embedding techniques has spurred the development of neural network-based approaches that better leverage context, forming the current focus of research in the area. It can be stated that this evolutionary process has progressively refined text analysis capabilities, enabling the sophisticated text analysis applications prevalent today.

Topic Modeling Algorithms

TM algorithms are typically categorized into three primary types based on their underlying mathematical approaches (Voskergian et al., 2024): (1) Algebraic models (e.g., LSA, NMF), (2) Probabilistic models (e.g., pLSA, LDA, and (3) Embedding-based models (e.g., Embedded Topic Model [ETM], BERTopic). Figure 3, presented in this chapter, adopts this classification to systematically illustrate the methodological diversity inherent in TM techniques. This categorization serves as a conceptual framework for comprehending the variety of approaches available within the field.

Figure 3

Basic Methodological Approaches of Topic Modeling Algorithms



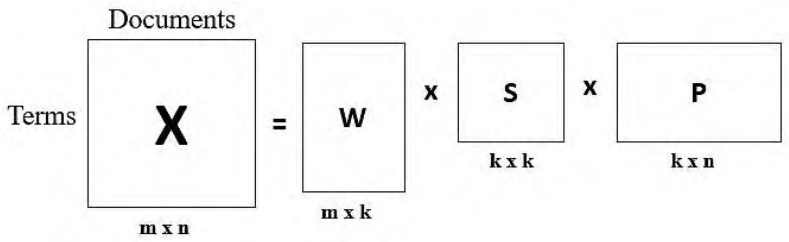
Algebraic Topic Models

Algebraic topic models comprise a class of algorithms that analyze text data principally through matrix factorization techniques. The most prominent algorithm within this category is LSA (Deerwester et al., 1990). LSA applies SVD to a document-term matrix, representing documents and terms within a lower-dimensional semantic space. Through this dimensionality reduction, issues such as polysemy and synonymy can purportedly be partially addressed, and latent thematic structures may potentially be uncovered (Chetia & Hazarika, 2019; Ren & Han, 2014).

Figure 4 summarizes the SVD process utilized within LSA. LSA begins with a large matrix (matrix X) that typically represents the frequency of words across documents. It decomposes this matrix into three parts (matrices W, S, and P in the convention of Figure 5) to generate lower-dimensional, meaning-oriented representations for words (matrix W) and documents (matrix P). This operation assists in identifying latent connections between words and documents, along with the principal topics (the number of which is determined by the parameter k).

Figure 4

Application of SVD in LSA model

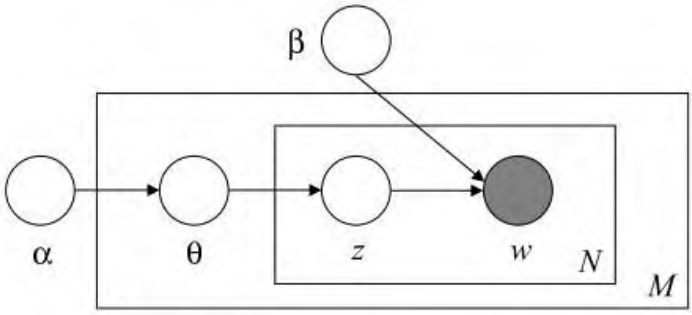


However, LSA's interpretability can be limited, and it may become computationally intensive on large datasets (Wang & Zheng, 2013). NMF, similar to LSA, employs a matrix factorization approach but aims to produce more interpretable results by enforcing that all values in the resulting matrices are non-negative (Koltcov et al., 2019). Notably, while both techniques utilize matrix factorization methodologies, NMF's constraints enhance clarity under specific conditions while potentially maintaining comparable performance metrics (Koltcov et al., 2019). Fuzzy Latent Semantic Analysis (FLSA), in contrast, attempts to model uncertainties by integrating LSA with fuzzy set theory. This integration enriches the semantic analysis process and allows for finer resolutions in meaning derived from ambiguous terms (Wang & Zheng, 2013).

Probabilistic Topic Models

Probabilistic topic models are approaches that model the underlying thematic structure of text collections based on probability theory and statistical inference methods. Central to these models is the assumption that each document is represented as a mixture of multiple topics, and each topic is defined by a probability distribution over specific words. One of the pioneering probabilistic models in this field, pLSA (Hofmann, 1999), introduced a solid statistical foundation to TM, in contrast to LSA's linear algebra-based approach. pLSA typically utilizes the Expectation-Maximization (EM) algorithm to estimate model parameters (topic-word and document-topic relationships) (Chehal et al., 2021). Thanks to the strong probabilistic framework it offers compared to LSA, pLSA has been reported to demonstrate effectiveness in topic extraction tasks and achieve performance advantages in some studies (Aznag et al., 2013).

Figure 5
Graphical representation of the LDA model



Source: Blei et al., 2003

Owing to its successful modeling capabilities and broad practical applicability, LDA continues to be one of the most widely used and popular techniques in the field of TM today (Hankar et al., 2025). The graphical model presented in Figure 5 outlines the fundamental operating principle of LDA. This model is predicated on the assumption that documents constitute a mixture of unobserved (latent) topics and that words are generated via these topics. The objective of LDA is to discover this latent topic structure from text data using statistical methods (Blei et al., 2003).

LDA models both the distribution of topics within documents and the distribution of words within topics by utilizing Dirichlet prior distributions. This feature enables the model to mitigate overfitting and generalize effectively to new documents. The Correlated Topic Model (CTM), in turn, extends LDA by explicitly modeling the correlations between topics (Blei & Lafferty, 2006). Such probabilistic models offer a flexible and powerful modeling capability by addressing the latent thematic structures in text data within a probabilistic framework (Masada & Takasu, 2013; Syahrial & Afidh, 2024).

Embedding-Based Models

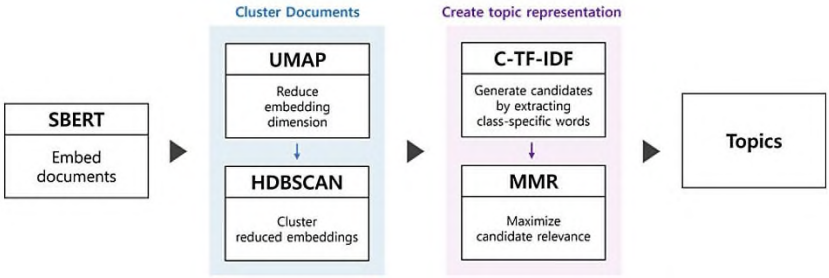
Aiming to uncover deeper semantic patterns and contextual relationships within texts, embedding-based TM introduces a novel perspective to the field by modeling the semantic content and relationships of words and documents through dense vector representations (embeddings). Approaches within this category exhibit diversity in their strategies for integrating embeddings. For instance, hybrid models like LDA2Vec concurrently learn word and topic vectors within the same semantic space by combining the interpretable structure of LDA with Word2Vec-like word embeddings (Moody, 2016). Approaches such as the ETM, while preserving a probabilistic framework, directly represent words and topics with embedding vectors, basing the probability of a word belonging to a specific topic on the similarity between the respective word and topic vectors (Dieng, Ruiz, and Blei, 2020). Other models, like CombinedTM, target the generation of more coherent topics by enriching Variational AutoEncoder (VAE)-based neural topic models with contextual embeddings from techniques such as SBERT (Bianchi et al., 2021).

Another significant group of embedding-based models, including TOP2VEC and BERTopic, addresses the challenge of pre-specifying the number of topics, often required as a hyperparameter. These models typically follow a distinct strategy: they first embed documents into a high-dimensional semantic space (using methods like Doc2Vec or SBERT, for example), then employ dimensionality reduction techniques such as UMAP, and finally utilize clustering algorithms like HDBSCAN to automatically detect densely populated regions of documents (i.e., the topics) (Angelov, 2020; Yang et al., 2024). While TOP2VEC defines the topic vector as the cluster centroid and identifies the nearest word vectors as the topic

words (Angelov, 2020), BERTopic, whose detailed workflow is illustrated in Figure 6, adopts a different approach. Instead of relying on cluster centroids, it employs a custom class-based TF-IDF (c-TF-IDF) variation for the documents within each cluster to derive more robust topic representations (Grootendorst, 2022). Such approaches, based on embedding and clustering, enable the flexible extraction of meaningful and interpretable topics from large text datasets.

Figure 6

The BERTopic algorithm workflow



The strengths and weaknesses of several commonly employed foundational algorithms in the TM domain, compiled based on relevant literature (Chehal et al., 2021; Egger & Yu 2022; Hankar et al., 2025), are summarized in Table 1. As illustrated, each algorithm possesses distinct advantages and disadvantages. For example, while LSA is effective for dimensionality reduction, it exhibits limitations regarding interpretability. Conversely, although the non-negative factors produced by NMF facilitate interpretation, the consistency of its results can sometimes be problematic. Similarly, despite offering a robust probabilistic framework, LDA may not demonstrate expected performance levels on short texts, and while CTM succeeds in modeling correlations between topics, it demands high computational costs. More recently developed models like BERTopic stand out for their contextual understanding and automatic topic detection capabilities, yet they entail disadvantages such as high computational resource requirements.

Table 1

Comparison of Advantages and Disadvantages of Major Topic Modeling Algorithms

Algorithms	**Advantages**:	**Disadvantages**:
LSA	· Dimensionality Reduction: Effectively reduces the dimensions of the term-document matrix	· Loss of Interpretability: The understandability of generated topics is low
	· Semantic Relationships: Captures synonymy and semantic similarity between words	· Lack of Context: Does not consider word order or context (BOW limitation)
	· Noise Reduction: Reduces noise in texts, creating more representative structures	· Limited Polysemy Support: Single-vector representation is insufficient for polysemous words
	· Partial Polysemy Resolution: Can partially address the polysemy problem	· Statistical Deficiency: Weak mathematical foundation, lacks a probabilistic framework
		· Computational Cost: Requires high memory and processing power

Algorithms	**Advantages**:	**Disadvantages**:
		· Optimal Dimension Uncertainty: Difficulty in determining the ideal number of dimensions for SVD
		· Topic Number Estimation: Cannot automatically determine the number of topics
NMF	· Non-Negative Factors: Non-negativity constraint enhances topic interpretability	· Inconsistent Results: Different initial setups may yield different solutions
	· Sparse Representation: Represents documents as topic clusters and topics as word subsets	· Missing Data Sensitivity: Requires preprocessing for incomplete data
	· TF-IDF Support: Term-document matrix can be weighted with TF-IDF	· Topic Number Requirement: User must predefine the number of topics
	· Implementation Ease: Easy to implement with low code complexity	· Coherence Issues: May produce topics with low coherence scores
	· No Prior Knowledge Needed: Does not require domain expertise	· Ambiguous Generative Model: Does not explicitly specify probabilistic model conditions
	· Mixed Membership: Allows multiple topics per document	
	· Computational Efficiency: Highly scalable	
LDA	· Probabilistic Framework: Complete generative probabilistic model for topic structures	· Predefined Topics: Requires manual topic number specification
	· Scalability: Effective performance on large document collections	· Short Text Limitation: Poor performance on brief document collections
	· Co-occurrence Analysis: Captures term relationships	· Preprocessing Sensitivity: Affected by steps like stop-word removal
	· Dimensionality Reduction: Superior to LSA and pLSA	· Correlation Blindness: Assumes topic independence (single Dirichlet)
	· Model Integration: Compatible with complex method combinations	· Evaluation Ambiguity: Lacks objective metrics
	· Hyperparameter Sensitivity: Produces coherent topics with proper tuning	· Topic Overlap: Soft clustering causes overlapping topics
	· Mixed Membership: Supports multiple topics per document	

Algorithms	Advantages:	Disadvantages:
CTM	· Topic Correlations: Models relationships between topics	· Computational Cost: Requires more processing power than baseline models
	· Multi-Topic Support: Single document can relate to multiple topics	· Interpretability Challenge: Difficult to understand topic correlations
	· Scalability: Handles large-scale document collections effectively	· Hyperparameter Sensitivity: Results affected by hyperparameter choices
	· Relationship Capture: Identifies thematic connections between topics	· Complex Relationship Limit: Cannot fully capture intricate inter-topic relationships
		· Inference Difficulty: Logistic normal distribution complicates multinomial approximation
		· General Word Issue: Topics may contain many generic/non-specific words
BERTopic	· Contextual Understanding: Captures term semantics via BERT embeddings	· Resource Intensive: Demands high memory and processing power
	· Dynamic Topic Detection: No need for predefined topic numbers	· Model Dependency: Quality depends on pretrained embeddings
	· Visualization Tools: Built-in topic distribution visualization	· Outlier Generation: Produces significant outlier clusters
	· Multilingual Support: Processes collections in multiple languages	· Rigid Assignment: Assigns single topic per document (no mixed membership)
	· Flexible Modeling: Offers dynamic, guided and class-based variants	·Evaluation Gap: Lacks objective evaluation metrics
	· Hierarchical Reduction: Enables hierarchical topic clustering	· Topic Proliferation: May generate excessive topics requiring manual review
	·Integrated Search: Facilitates topic-document navigation	

The fact that algorithms possess such distinct strengths and weaknesses highlights the critical importance of choosing the most appropriate method for a given research problem and dataset. Table 1 aims to provide guidance to researchers during this selection process. However, it must be emphasized that the performance of any given algorithm can vary significantly depending on the characteristics of the dataset used, the preprocessing steps applied, and the parameters selected. Therefore, prior to making a final algorithm selection, it is advisable to empirically evaluate and compare different approaches on the specific problem at hand.

Application Domains with a Human Focus

The preceding sections have addressed the definition, historical development, and foundational algorithms of TM. From a technical standpoint, these methods possess the powerful capability to uncover meaningful patterns by extracting information from large collections of unstructured text. Following these technical foundations, this section will delve into the diverse domains where TM is applied. Its capacity to structure and interpret textual data renders it valuable across a wide spectrum of disciplines, ranging from the social sciences and health to software engineering, business, and media analysis. This part will illustrate, through examples, how TM is applied to concrete problems within these distinct fields and the kinds of outputs it can provide.

Social Sciences and Communication Research

Social sciences and communication research significantly leverage TM's capability to reveal latent structures and trends within textual data. These techniques can be employed to understand societal trends, political discourse, cultural shifts, and public sentiment by analyzing large-volume text collections such as social media data, survey responses, historical documents, or media content (Maier et al., 2018; Puschmann & Scheffler, 2016). For instance, TM has been applied to examine the historical evolution of the field of economics and its structural changes over a specific period, tracking how the most relevant topics discussed by economists shifted across decades (Ambrosino et al., 2018). Similarly, methods like LDA have been utilized to explore trends, research areas, and gaps within transportation research, identifying temporal changes in topics such as sustainability and travel behavior (Sun & Yin, 2017; Zhu & Chowdhury, 2019). Furthermore, during the COVID-19 pandemic, topic-based sentiment analysis was conducted on social media comments in an effort to understand public reactions and concerns (Hankar et al., 2022). Such analyses enable the mapping of the intellectual structure within specific fields, the identification of research agendas, and a deeper understanding of societal processes.

Business and Market Analysis

For businesses, TM constitutes an effective tool for gaining valuable business intelligence from customer feedback, product reviews, and market data, thereby informing strategic decision-making. Analyzing data sourced from channels such as online customer comments or social media posts aids in understanding the general perception of a company or product, as well as the primary themes related to customer complaints or satisfaction (Jeong et al., 2019; Zhu & Chowdhury, 2019). For example, sentiment analysis performed using LDA on film reviews from platforms like IMDB has yielded successful results (Farkhod et al., 2021). In specific sectors, such as the airline industry, sector-specific business intelligence has been discovered by applying TM to customer reviews (Srinivas & Ramachandiran, 2020). It is also known that large-scale industrial applications, such as search engines and online advertising systems, utilize LDA-based models incorporating hundreds of thousands of topics to serve millions of users (Wang et al., 2014). Such analyses contribute to companies' abilities to better meet customer needs, improve their products, optimize marketing campaigns, and ultimately enhance their competitive edge.

Health and Bioinformatics

The fields of health and bioinformatics extensively leverage TM for the analysis of large and complex textual data, such as electronic health records (EHRs), scientific publications, and genetic data (Liu et al., 2016). These techniques have been employed in diverse tasks, including analyzing the overall structure of the bioinformatics field (Heo et al., 2017), analyzing and classifying gene sequences (La Rosa

et al., 2015), and classifying gene expression data (Kho et al., 2017). Furthermore, text from social media platforms such as Twitter has been analyzed using the BERTopic model, achieving successful outcomes in specific health-related tasks like the classification of cognitive distortions in Arabic text (Alhaj et al., 2022). Topic-based sentiment analysis of social media commentary during the COVID-19 period also emerged as a significant application area for understanding public health perception (Hankar et al., 2022). TM assists researchers and clinicians in these fields in discovering patterns within large datasets, acquiring new knowledge about diseases, identifying potential therapeutic targets, and synthesizing scientific knowledge.

Education

In the field of education, TM and related text mining techniques offer valuable tools for understanding learning processes, student experiences, and research trends within the discipline. To identify challenges faced by students or educators, unstructured text data such as support request (ticket) records can be analyzed to detect common problems and needs (Irmak, 2023). Similarly, TM is utilized to map research topics and their temporal trends within specific educational domains, such as environmental education. In one such study, LDA and other text analysis techniques were applied to the abstracts and keywords of research articles to reveal core research themes and shifts within the field (Chang et al., 2021). These analyses allow not only for the understanding of general educational trends or issues but also enable a more detailed grasp of learning difficulties, misconceptions, or areas of interest derived from data like student essays or forum discussions. The findings obtained can assist educators in adapting their teaching strategies, improving course materials, and designing more personalized learning experiences for students.

News Analysis and Media

News analysis and media research utilize TM to analyze extensive news archives, social media streams, and other media content. These analyses are valuable for understanding how specific events or topics are framed by the media, identifying the main themes in public discussions, tracking shifts in the agenda, or comprehending the diffusion of misinformation (Maier et al., 2018; Puschmann & Scheffler, 2016). For example, techniques such as Doc2Vec combined with spherical clustering have enabled the unsupervised grouping of news articles according to their topics (Budiarto et al., 2021). TM allows journalists, researchers, and policymakers to monitor trends within the information environment more systematically and gain a better understanding of public perception. This can contribute to more informed journalism, facilitate in-depth analyses in media studies, and foster healthier public discourse.

Natural Language Processing and Information Retrieval Tasks

TM is also a technique frequently employed in foundational NLP and IR tasks. Various TM approaches have been successfully applied in applications such as word sense disambiguation (Brody & Lapata, 2009), multi-document summarization (Haghighi & Vanderwende, 2009; Wang et al., 2021), text segmentation (Sun et al., 2008), document classification and categorization (Alhaj et al., 2022; Aubaid & Mishra, 2020;Budiarto et al., 2021; Christian, 2024), opinion mining (Kim et al., 2020), and automatic term extraction (Anoop et al., 2016; Nugumanova et al., 2022). The demonstrated efficacy in these core tasks allows TM to serve as an underpinning for more complex applications centered on human needs and interactions.

Software Engineering

The field of software engineering also leverages TM to analyze the substantial volume of textual data generated during software development processes, such as source code comments, bug reports, requirements documents, and discussion forums. These techniques have been employed in various tasks, including source code analysis and feature location (Dit et al., 2013), improving software testing processes (Hemmati et al., 2017), establishing relationships between requirements and implementation within requirements engineering (Hindle et al., 2012), and understanding software architecture (Garcia et al., 2011). TM can aid software development teams in gaining a better understanding of the codebase, identifying defects more rapidly, managing requirements more effectively, and enhancing overall software quality.

Conclusion

This book chapter has comprehensively examined TM, a technique playing a critical role in the process of extracting meaningful information from large text collections. It has been observed that TM, whose fundamental principle involves discovering latent thematic structures within textual data, offers a robust framework for the comprehension, organization, and interpretation of unstructured information.

The chapter traced the historical evolution of the field, commencing with early algebraic approaches like LSA, progressing through the statistical rigor introduced by probabilistic models such as pLSA and notably LDA, and culminating in the emergence of contemporary embedding-based techniques (e.g., ETM, BERTopic) that better capture contextual information. This trajectory has illustrated the continuous development and diversification of text analysis capabilities. Furthermore, the methodological distinctions and operational principles of foundational algorithms including LSA, NMF, LDA, and BERTopic were reviewed, highlighting the unique advantages and disadvantages of each and emphasizing the importance of appropriate algorithm selection tailored to the specific problem and dataset.

The practical value of these technical approaches was demonstrated through concrete application examples across diverse domains, including the social sciences, business, health, education, media analysis, NLP, and software engineering. The applications examined in detail within this chapter clearly reveal TM's potential that extends beyond being merely a technical analysis tool; it encompasses understanding societal trends, informing decision-making processes, accelerating scientific discovery, personalizing learning experiences, and ultimately enriching human experience.

In conclusion, TM stands out as a valuable and indispensable approach in today's world, characterized by ever-increasing volumes of unstructured text data, for achieving a deeper understanding and interpretation of information, ultimately leveraging it for human benefit. The insights afforded by these techniques hold significant potential for contributing to the vision of a "human-centered future," which constitutes the central theme of this book.

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Chapter 21

Utilization of Learning Analytics in Massive Open Access Courses

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Abstract

In the 21st century, a period characterized as the age of technology, various discoveries are being made in the field of educational technologies. Particularly, Learning Analytics is acknowledged as a significant research area in Technology-Enhanced Learning. In this context, online learning platforms such as Massive Open Online Courses (MOOCs) draw attention by providing analysis, comparison, examination, and improvement techniques. MOOCs are online courses targeting a wide learner community, and due to the inclusion of differences such as age, gender, psychological profile, social context, and educational level among the participants, they constitute important datasets. These data are considered a valuable resource in the field of Learning Analytics. This study, based on a literature review, examines the methods, benefits, challenges, and current MOOCs in Türkiye implementing Learning Analytics applications. The challenges encountered in MOOCs and the detailed explanation of the role of learning analytics, along with the benefits obtained, are presented. The literature review indicates that methods such as data mining, statistics and mathematics, text mining, semantics-linguistics analysis, visualization, social network analysis, and gamification are applied to Learning Analytics in MOOCs. It is suggested that these methods will be implemented in MOOCs in Türkiye in future studies.

Keywords Learning analytics · e-learning · distance education · MOOCs

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Introduction

Learning Analytics is a research discipline that is rapidly evolving and aims to conduct detailed analyses of learning and learning environments to optimize them (Saqr, 2018). E-Learning Platforms, especially Learning Management Systems (such as Moodle, Sakai), and MOOCS platforms (such as edX, Udacity, Coursera), are becoming increasingly prevalent tools among educators. These platforms are used to support learning, integrate technology into educational processes, effectively deliver information to students, and enhance the quality of education.

In this context, the need for various analyses to monitor system usability and changes in student performance becomes evident. Thus, the concept of Learning Analytics has emerged in conjunction with Technology-Enhanced Learning, involving data analysis and the use of various metrics in educational processes (Bahçeci, 2015).

In today's era, the concept of educational technologies is becoming more widespread, emphasizing the growing importance of teachers and instructors effectively using technology and advanced tools to increase student motivation and engagement. Globally, the adoption and implementation of new teaching skills are crucial in the transformation of education (Chang et al., 2018).

In the context of this study, the aim is to provide a general overview of the existing concepts and methods of learning analytics associated with MOOCs. At the conclusion of the study, a literature review will be compiled on MOOCs and learning analytics concepts, presenting the functionality of learning analytics tools in future MOOCs.

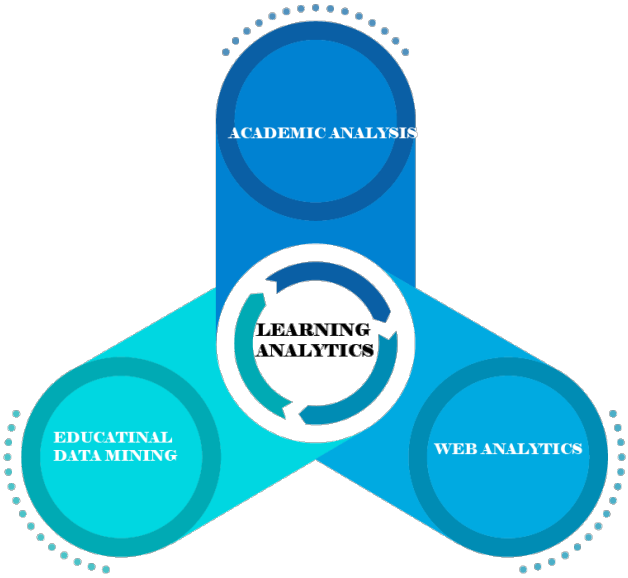
Learning Analytics and MOOCS

The term Learning Analytics, which emerged at the International Conference on Learning Analytics and Knowledge (LAK2011) and was grounded by the Society of Learning Analytics (SoLAr), refers to a research discipline aimed at understanding and optimizing learning and the environments in which this process takes place (Elias, 2011; Siemens, 2013). According to this definition, learning processes and contexts are examined in detail through the measurement, collection, analysis, and reporting of data related to students.

The learning process is a complex one that involves not only interactions among students but also social interactions among teachers, instructors, and other stakeholders. Educators make efforts to maximize these interactions and improve learning designs. As a result of these efforts, questions arise regarding the effectiveness of the course, meeting learner needs, and how education can be enhanced. The answers to these questions are found through statistical evaluation and analysis of data obtained through big data analysis, facilitated by learning analytics (Ellias, 2011).

The first learning analytics conference, held in Banff, Canada, in 2011, aimed to explore and develop learning analytics by bringing together researchers from around the world (Dawson et al., 2019). Since then, there has been unprecedented development in learning analytics on education and learning platforms. This emerging field has demonstrated close relationships with areas such as web analytics, educational data mining (EDM), and academic analytics (Bozkurt, 2016). As depicted in Figure 1, these interconnected domains collectively underpin and advance the development of learning analytics as a multidisciplinary field.

Figure 1
Learning Analytics



Distance education has undergone a significant transformation with the significant advancements in the internet and technology fields today. This form of education has facilitated users' access to information more easily and extensively, transforming learners into active participants who individually access, produce, shape, and analyze information. The ease of access to information has supported the emergence of MOOCs, enabling many individuals to receive education simultaneously. The term MOOC was first used by Stephen Downes and George Siemens in 2008 and gained popularity in 2011 when Stanford University professors shared educational videos on free online learning platforms (Baturay, 2015).

MOOCs generally support models of free learning and independence from time and place. Additionally, they track and examine students' successes and failures. This model provides broad access to participants, at least through free accessibility. The concept of MOOCs is based on the following key characteristics:

Massive: The term "Massive" implies vastness and greatness in English. It signifies the participation of a large number of students in MOOCs. Courses can start with 100 participants and expand up to 100,000. With this understanding of massive participation, the concept of a global classroom emerges as it transcends educational boundaries. Factors such as learner variations, educational materials, and the network of access are crucial in this context (Bozkurt, 2016).

Open: The term "Open" symbolizes the freedom of any individual with internet access to participate in this education. Students are free to receive the education they desire, engage in interactions, and conduct analyses. The prerequisites for participation are limited or nonexistent (İnan et al., 2020).

Online: In the MOOCs model, administration, data systems, and education are entirely delivered online. There is no physical location, and all education is conducted through courses that are accessible online and delivered via the web (Khail, 2018).

Course: The term "Course" indicates that within the educational plan created by instructional designers, the contents of lessons are structured with pedagogical approaches. Each course includes instructional materials and interactive content aimed at imparting knowledge on specific topics to students. This provides students with the opportunity to gain and apply knowledge on a particular subject, making the education process more interactive and participatory.

Türkiye, the development of MOOCs is still in its early stages, with several key universities and private initiatives making strides toward expanding online education. Anadolu University, a pioneer in this area, launched the AKADEMA platform in 2013, initially offering eight courses primarily in social sciences and humanities. This initiative has reached over 2,000 learners and operates on a custom-developed infrastructure, marking a significant step in Türkiye's e-learning ecosystem Following this, Atatürk University in Erzurum established ATADEMİX, a Moodle-based platform offering 14 courses in Turkish, with further courses under development to increase access to education for a wider audience In the private sector, Yaşar University has made several of its online courses available as self-paced MOOCs, though without certification, providing 17 courses to learners through its platform Another private institution, Koç University, took a different approach by translating global Coursera courses into Turkish and launching its own course in 2014, thereby contributing to the diversification of available MOOCs in Türkiye Additionally, Turkcell, a leading telecommunications company, has supported the creation of three MOOCs on EdX, further expanding the reach of digital learning in Türkiye .Moreover, the initiative UniversitePlus has emerged, offering a platform akin to Coursera and collaborating with multiple universities and profit-driven entities to provide 46 courses, marking a collaboration between academic institutions and private initiatives in delivering MOOCs. These various efforts underscore Türkiye's growing commitment to expanding access to higher education through MOOCs, although challenges like infrastructure limitations and resource constraints continue to hinder widespread adoption. Nonetheless, the increased involvement of both public universities and private entities highlights a positive trend toward integrating Learning Analytics and other data-driven methods to enhance learning outcomes in the digital era (Akgül 2018).

Research Design

This research aims to comprehensively explain the methods, advantages, and challenges of utilizing learning analytics in the evaluation of extensive datasets in the field of MOOCs. Understanding how learning analytics can be effectively implemented in MOOCs is one of the key objectives of this study. In this context, the research focuses on two main research questions that determine its central points. The question form the foundation of the review and are as follows:

RQ1. What are the methods for implementing learning analytics in MOOCs?

The answer to this question begins by providing an overview of learning analytics and MOOCs, followed by an in-depth examination of the methods used for applying learning analytics in MOOCs, including data mining, statistical methods, and visualization techniques.

RQ2. What are the benefits and challenges of implementing learning analytics in MOOCs?

This question will explore the advantages and challenges faced by educators, administrators, and students when applying learning analytics in MOOCs. The study will assess how these tools contribute to student engagement, success, and course improvement, as well as the difficulties in managing large datasets and ensuring data privacy."

The answer to these questions begins by providing an overview of learning analytics and MOOCs. Examining trends in learning analytics in MOOCs in detail, the response will serve as a guide for future research. The research is built upon a comprehensive literature review that explores key concepts such as "Learning Analytics" and "MOOCs."

In this context, to identify the methods, benefits, and challenges of learning analytics in MOOCs, studies published in peer-reviewed journals, encompassing quantitative, qualitative, mixed methods, and other literature reviews, have been analyzed in detail. The literature review covered articles published between 2012 and 2022, ensuring a focus on the most recent advancements in the field.

The review utilized full-text searches in both Turkish and English using important databases, including Scopus, Semantic Scholar, Web of Science, Google Scholar, ResearchGate, Yök-Tez, and Dergipark. A total of 45 studies were examined, addressing topics such as the implementation of learning analytics methods, the evaluation of learner engagement, and the optimization of teaching strategies in MOOCs

Literature Search Results

Data Science is a broad discipline that aims to derive meaning from various processed or unprocessed types of data. The fundamental goal in this field is to analyze data, transform it into information, and direct this information towards understanding, prediction, or decision-making processes. Learning Analytics, on the other hand, is a subfield that specifically aims to generate knowledge by utilizing the vast scope of data science, especially in the context of education. Learning Analytics encompasses numerous disciplines such as computer science, statistics, data mining, machine learning, and human-computer interaction, utilizing these disciplines to optimize educational processes (Piety et al., 2013).

MOOCs, represent educational environments with rich data sources where learning analytics can be particularly effectively applied. Unlike traditional classrooms, MOOCs include a diverse student population, and the various interactions, participations, and performances of these students create extensive datasets. This situation provides a significant advantage for implementing learning analytics because these data offer information on a scale and diversity not achievable in traditional classrooms (O'Reilly and Veeramachaneni, 2014).

By examining student behaviors in MOOCs, Learning Analytics can assist educators in improving teaching strategies. Understanding student behaviors is a crucial step in optimizing teaching processes, enhancing student success, and making continuous improvements in education. In this context, learning analytics employs various analysis methods to understand what students are learning online, identify challenging topics, and determine effective learning strategies.

Learning Analytics adopts an interdisciplinary approach, integrating not only technical and statistical analyses but also disciplines such as psychology, educational science, and pedagogy. This integration helps develop a deeper understanding of student success, learning processes, and teaching strategies.

In MOOCs, learning analytics extensively examines student behaviors using various methods such as data mining techniques, statistics and mathematics, text mining, natural language processing, visualization, social network analysis, and gamification (Khalil and Ebner, 2016). These methods are used to understand student interactions, learning progress, and engagement levels, enabling educators to provide better guidance to students, optimize courses, and enhance student success using the gathered insights.

Learning Analytics Methods and Applications

Learning Analytics holds a significant position in the dynamic and data-rich landscape of modern education. The rapid advancements in this field underscore the efforts to harness the potential of education by analyzing data derived from student behavior. Integrating information technologies

and analytical methods, Learning Analytics aims to enhance educational processes, elevate student success, and optimize teaching strategies. The methods within Learning Analytics explored in this context offer the capacity to comprehend student behavior and effectively manage learning processes using extensive datasets. Evaluation of parameters such as student achievement, interaction patterns, content interactions, and time management enables educators to respond more precisely to individual student needs. Student-focused data analytics becomes a potent tool for educators, facilitating a deep understanding of students' unique learning paths and the development of personalized educational strategies. An exploration of the fundamental principles of Learning Analytics and a closer examination of the diverse methods and applications in this realm contribute to our comprehension of the data-driven transformation occurring in education.

Data Mining

Data Mining is a methodology used to explore new learning areas beyond traditional learning methods for students. Its main objective is to understand existing data and optimize learning processes using this data. Particularly in the context of MOOCs, data mining can be employed to investigate the impact of students' emotional states and actions on their learning performance (Tucker et al., 2014).

In the field of e-learning, data mining is often integrated with classification and regression approaches. In MOOCs, previous data is analyzed and determined to predict future behaviors and attitudes. This enables accurate classification, yielding precise results from the data. Additionally, Data Mining can be effectively applied in MOOCs thanks to its integration into e-learning environments. This method employs various techniques such as prediction, classification, association rules, clustering, and fuzzy logic to obtain important information in MOOCs (Abd Elaal, 2013).

The use of Data Mining in MOOCs enriches learning analytics and allows for more effective management of learning processes. This methodology stands out as a significant tool for understanding student behaviors, improving learning processes, and optimizing educational strategies.

Statistical and Mathematical Methods

Analyses conducted on students' educational backgrounds aim to examine the relationships between participation rates and gains using statistical and mathematical methods. This method enables the identification of students with low participation in education based on numerical data. Especially in the context of MOOCs, various data such as students' online durations, activity statuses, visited pages, and materials they read and watch are stored within the system.

Statistical and mathematical methods are used to analyze students' behaviors and actions based on this data. The examination of learners' behaviors in the system is conducted through various statistical and mathematical analyses. These analyses are employed to provide a comprehensive understanding of student interactions, participation levels, and learning processes. Simultaneously, they offer significant information to educators in terms of increasing motivation in education and developing instructional strategies (Al-Shabandar et al., 2018).

This data analysis in MOOCs allows for a detailed examination of the behaviors students exhibit on online platforms. These analyses encompass a range of critical parameters, including student interactions, participation levels in learning activities, achievements, and challenging topics. This enables the identification of strengths in the learning processes, the development of strategies to improve student performance, and a focus on weaknesses in education. Statistical and mathematical methods facilitate data-driven decision-making to enhance student success and improve the quality of education.

Text mining- Semantics-Linguistic Analysis

The data obtained from content created by instructors and discussion sections in forums can be thoroughly examined through the Text Mining-Semantic-Linguistic Analysis method. This analysis serves as a crucial tool in evaluating educational outcomes in the context of MOOCs and obtaining realistic results through research and analyses in discussion sections of forums (Wen et al., 2014).

Various techniques are employed during the application of this method. For example, the summarization technique performs the summarization process accurately by reducing the length of texts. The categorization technique is used in the classification of technical documents, while information extraction technique aims to obtain valuable information from the text, gather knowledge, and Clustering Technique includes techniques used in the analysis, collection, and stacking of texts (Dang & Ahmad, 2014).

Text mining and linguistic analysis are of great importance in providing in-depth information about students' learning processes. These methods are used to understand how students respond to educational content, improve learning processes, and make educational materials more effective. Additionally, these analyses enable educators to optimize their teaching strategies by providing valuable information about student feedback, needs, and potential issues.

Visualization

The visualization method, a crucial component of learning analytics applications in the field of MOOCs, enables the effective interpretation of obtained data. This method supports a more in-depth analysis of educational processes and data in MOOCs, providing users and researchers with the opportunity to gain meaningful insights into education and conduct detailed analyses (Gama & Gonçalves, 2014).

Visualization plays a critical role in understanding the complexity in education and MOOCs data, making these data more accessible and meaningful. Visualizing data allows complex information to become more understandable, enabling education professionals, students, and researchers to present data that may be challenging to comprehend in a more explanatory manner.

This technique is also employed to enhance learning processes, brainstorm, and stimulate creativity. Various visualization methods can be used to make educational materials more effective and engaging. Examples such as mind maps, concept maps, cognitive maps, radial trees, semantic maps, root structures, visual metaphors, tree structures, argument maps, and social maps showcase the diversity and applications of these methods (Latha et al., 2016).

As a fundamental element of e-learning applications, visualization is a powerful tool to deepen the understanding of data in education and optimize education for a broader audience. By presenting complex information in a more understandable and interactive manner, this method provides valuable insights to decision-makers in the field of education.

Social Network Analysis

Social Network Analysis is an analytical method used to understand relationships among data obtained in research and interpret interactions in communication tools (Perovic, 2015). This method has gained significant importance, especially in the field of Learning Analytics, and has become a preferred tool by many researchers aiming to better understand and optimize educational environments.

By providing the opportunity to comprehensively examine learning processes and interactions, Social Network Analysis contributes to the understanding of the social structures and interactions

in learning environments. This analytical method allows for a detailed observation of connections, interactions, and knowledge sharing among students.

The in-depth analysis of network structures offers a valuable perspective for understanding connections and interactions among students. As a result, education professionals can better assess relationships among students and optimize learning environments accordingly.

Social Network Analysis serves as a powerful research tool, offering a comprehensive perspective to understand and enhance educational participation interactions. This method is employed to comprehend social dynamics in learning processes, increase interactions among students, and develop more effective educational strategies.

Gamification

The gamification method is a strategy aimed at making learning processes more effective and enjoyable. This method plays a crucial role in increasing student motivation, strengthening interest in learning platforms, and encouraging participation in courses, especially in MOOcs and online learning environments (Saleem et al., 2021).

Since MOOCs are filled with a diverse participant base and individuals with different learning styles, there is diversity in participation and completion levels among students. Gamification is an effective strategy to address this diversity and engage students more deeply in the educational process. By incorporating fundamental gaming features, reward systems, and competitions, gamification makes the learning process more engaging and interactive. Rewards provided to students, celebrating achievements, and competitive elements enhance student motivation, thereby increasing their interest in learning. This strategy ensures that students actively participate in the learning process. Gamification makes educational materials more appealing, capturing students' attention and making the learning process immersive. Through game-like learning experiences, students gain a deeper understanding of topics and develop a positive attitude towards learning.

In conclusion, gamification applications in MOOCs lead to a more interactive, enjoyable, and successful learning experience with high levels of student motivation and participation. This method supports student-centeredness and interactivity in education, making learning more enjoyable and efficient.

These elements not only enhance engagement but also allow Learning Analytics systems to track student performance in real-time, providing educators with actionable insights into learner progress and areas needing intervention (Deterding et al.,2011). In their study, Cassano et al. (2019) investigate the synergistic use of gamification and learning analytics to foster greater student engagement in university courses. The authors argue that while gamification introduces motivational elements, such as rewards and challenges, it is the incorporation of learning analytics that provides actionable insights into students' behaviors and progress. This integration allows for real-time adjustments, enhancing the personalization of learning experiences. By combining the engaging power of gamified structures with data-driven decision-making from learning analytics, the study demonstrates how these methodologies can significantly improve student participation, satisfaction, and overall academic performance. The findings underscore the importance of a data-informed approach in maximizing the effectiveness of gamification within academic settings.

Table 1 summarizes the various methods and techniques used in Learning Analytics for MOOCs. These methods include Data Mining, Statistical Methods, Text Mining, Visualization, Social Network Analysis, and Gamification, each contributing uniquely to improving student engagement and success in MOOCs.

Table 1

Learning Analytics Implementation Methods and Techniques in Massive Open Online Courses (MOOCs) (İnan & Ebner, 2021)

Method	Techniques	Explanation	Examples
Data Mining	Predictions, Classification, Clustering, Fuzzy Logic	Data mining methods are used to analyze student data and predict future behaviors or categorize students based on their learning patterns.	Predicting student success, clustering students by engagement level.
Statistical Methods	Mean, Mode/Median, Standard Deviation, Markov Chain	Statistical methods are employed to analyze the relationships between participation rates and academic performance in MOOCs.	Analyzing participation vs. academic success, identifying struggling students.
Text Mining	Summarization, Categorization, Clustering	Text mining analyzes textual data such as forum discussions or course materials to extract meaningful insights about students' learning.	Analyzing forum posts to identify common learning difficulties, categorizing student feedback.
Visualization	Mind Maps, Concept Maps, Cognitive Maps, Tree Structures	Visualization techniques help to represent complex data in a more digestible format, facilitating easier comprehension of student progress and engagement.	Visualizing learning progress through concept maps, creating a tree structure of course content.
Social Network Analysis	Block Modeling, Dynamic Network Analysis	Social network analysis studies interactions between students to understand how they collaborate and learn in social contexts, identifying key influencers in the group.	Analyzing student interactions on forums or social media platforms to understand collaboration.
Gamification	Reward Systems, Failure Analysis, Rapid Feedback, Progress	Gamification adds game-like elements to the learning process, such as rewards, challenges, and feedback, to increase engagement and motivation.	Implementing point systems, providing badges for achievements, setting time-based challenges.

Advantages and Disadvantages of Learning Analytics in MOOCs

The integration of Learning Analytics with MOOCs yields a range of benefits alongside associated challenges, warranting a comprehensive examination. A nuanced analysis of these facets contributes

to a deeper comprehension of how this amalgamation effectively manages learning processes and enhances student success.

MOOCs, serving as versatile online learning platforms, accumulate extensive datasets that encompass various dimensions of student engagement, performance, and interactions. These datasets constitute the raw material for Learning Analytics, spanning from basic metrics like mouse clicks to more intricate aspects, such as student interactions, real-time and post-test performances, login patterns, duration of active engagement, and interactions with diverse course materials. The application of Learning Analytics transforms this diverse dataset through the analytical process, rendering it a valuable resource capable of directly impacting student success and elevating the overall quality of education. These datasets constitute the raw material for Learning Analytics, providing a wide range of opportunities as well as challenges for implementation (Chiam, 2016).

Employing Learning Analytics within the context of MOOCs brings forth manifold advantages. These include predictive capabilities, personalized recommendations, effective data visualization, incorporation of entertaining elements, comparative analyses, personalized learning experiences, increased engagement, leveraging communication information, and potential cost savings, all of which contribute positively to various dimensions of the educational experience (Khalil et al., 2016).

The symbiotic relationship between Learning Analytics and MOOCs empowers students to assess and interpret their own performance, providing instructors with tools to influence the learning experiences of individual students or groups. Administrators also stand to benefit significantly by gaining insights into curriculum enhancements and identifying areas where students may be facing challenges (Avella et al., 2016).

However, the application of Learning Analytics in MOOCs is not without its challenges. It extends beyond mere data collection, requiring intricate processes of data transformation, interpretation, and accurate understanding. The complex nature of the learning process, coupled with cultural factors, necessitates a meticulous effort to comprehend and interpret the nuances of various educational models.

Ferguson's (2012) identified challenges include establishing robust connections with learning sciences, grappling with the intricacies of understanding and optimizing learning environments and MOOCs, the ongoing challenge of prioritizing the student's perspective, and the difficulty in formulating and implementing a clear set of ethical rules.

Looking ahead, technological advancements and the continued evolution of platforms are anticipated to assist in overcoming these challenges. Learning Analytics and MOOCs represent dynamic fields that not only keep pace with scientific contributions to education and learning but also continually strive to enhance the learning environment through ethical considerations, improved security, and enhanced data control measures.

Results

Learning Analytics is a concept that is dynamic and continuously evolving. At the core of this evolution, the impact of MOOCs, which have large data sources used to understand and optimize learning processes in depth, is of great importance. This study comprehensively explains how learning analytics is applied in MOOCs, covering the latest methods in data mining, statistics and mathematics, Text Mining, Semantics-Linguistics Analysis, visualization, Social Network Analysis, and Gamification.

Data mining enables the extraction of meaningful patterns from learning data. Statistics and mathematics assess learning processes using numerical data when analyzing student performance. Text Mining is employed to understand student emotions and thoughts by analyzing text data extracted from

student forums or documents. Semantics-Linguistics Analysis evaluates students' topic understanding by examining the structural elements of language.

Visualization transforms learning data into a meaningful and accessible format through graphics or diagrams, assisting educators and students in making better decisions. Social Network Analysis is used to understand student interactions and communication networks. Gamification makes the learning process more engaging and fun by adding game elements, which can enhance student motivation.

However, there are challenges in the implementation of these methods. Issues such as data security, ethical considerations, and the complexity of learning processes come to the forefront. In the future, learning analytics and big data will be more widely adopted to gain a more effective understanding of how learning occurs in MOOCs and to use this information to enhance student success.

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