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# SOCIAL IMPACT OF DATA BIAS IN ARTIFICIAL INTELLIGENCE MODELS

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Abstract: *The growing popularity and scope of application of artificial intelligence models requires attention to be paid to their reliability and the explainability of the reasons behind the results and recommendations they generate. Widespread automation driven by the development of AI may have serious social consequences, and data bias may be the cause of unethical and socially unacceptable tendencies in models. This can manifest itself both at the stage of data collection and processing, but also during model training or implementation. It is the duty of the scientific community not only to pay special attention to exposing the biases of models, but above all to track down unacceptable implementations and strive to take into account the social consequences of the technological solutions being developed. In this study, we will look not only at the causes of bias, but also at examples with significant social implications and measures aimed at eliminating bias and its social consequences.*

Keywords: *data bias, social consequences, bias examples, bias mitigation.*


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## INTRODUCTION

The popularity and declared effectiveness of artificial intelligence models have become the driving force behind contemporary technological and social changes. The automation of industrial processes and the gradual reduction of human involvement in decision-making, as well as the increasingly widespread generation of opinion-forming content and advertising, are diverting humanity's vigilance and attention away from the bias of AI models. The classic AI evaluation system, based on measures such as accuracy, effectiveness and precision, does not allow for an assessment of their reliability, especially given the rather limited access to the learning algorithms and data used in AI model training.

It is important to be aware that artificial intelligence models attempt to find patterns in the space of features and accompanying observations. What happens when features or observations are underrepresented or do not take certain perspectives into account? What tendencies does a model have when biased data is used? Intuitively, one could respond that data-dependent artificial intelligence models take on the characteristics of the data itself and its interpretation. Regardless of the quality of the data, the vulnerability of artificial intelligence models may result from the learning process itself, e.g. the attention mechanism or cost function allow the model's output to be biased in order to encode the creator's intentions. Model biases may also result from runtime data and not just the data on which the model was trained.

However, this does not change the fact that data is the most common cause of model bias, which is why we will take a closer look at different types of bias. We can distinguish several types of bias. The most common is selection bias. It occurs when the training data is not representative of the population. Outlier bias is a certain complement to this, where we focus on general trends and ignore rare and unusual events, distorting the spectrum of possible observations. Equally common, although users are much less aware of it, is confirmation bias. It occurs when the AI model's behavior confirms our existing attitudes or beliefs, especially since we usually like to be right, and algorithms have learned to confirm this. It is often similar to historical bias, where data is overly dependent on historical prejudices or stereotypes. Measurement bias, on the other hand, occurs when the data collected systematically fails to reflect the actual variables and dependencies of the process. Either we focus on selected (most frequent and therefore accessible – availability bias) aspects, ignoring those we consider less important, or we do not consider the full spectrum of variants, focusing only on successes and not analyzing cases of failure (survivorship bias).

Despite numerous deficits in the available data sets, stakeholders seem so strongly guided by their own priorities that data bias is usually not overestimated. On the one hand, scientists are competing, sometimes blindly, to achieve the best results, but without paying due attention to the interpretability/explainability of the solutions obtained. Overfitting the model does yield better results, but only on the data set used. Verifying the solution on a different data set usually reveals its imperfections. However, examining the origin of the result requires reflection and time, which not everyone is willing to invest. Driven by the desire for profit, industry representatives are trying to commercialize the available knowledge without concern for the ethical aspects of AI models. It is not difficult to imagine a situation where a potentially greater material benefit would encourage the creators or users of AI models to manipulate the data or the model itself in order to achieve their intended goal. On

the other hand, ordinary users view everything with a mixture of fear of change and possible job loss, but on the other hand, they want to opportunistically use the available tools to make their work easier. However, they tend to forget that they are acting as unpaid laborers, sacrificing their free time to feed the algorithms of large language models or social media.

Let us therefore look at selected examples of bias in the available solutions and then consider whether we can influence this. As researchers or journal editors, can we increase our diligence in striving to reduce the bias of AI models and increase their reliability?

## DATA BIAS EXAMPLES

One area that is not free from critical examples of AI bias is healthcare. Rickman et al. (2025) analysed the tendency of selected LLMs to automatically summarize long-term care cases in a sample of the British population. The performance of four language models (Llama3, Gemma, T5, BART) was verified among more than 600 elderly people. Gender bias was observed in some models, with summaries of men focusing more on physical and mental issues than those of women and being formulated in a more direct manner. In this way, women's needs may be overlooked more often than men's. Unfortunately, examples of gender-based social injustice are much more common. According to The Times[1], Apple credit card holders (formally managed by Goldman Sachs) have repeatedly reported that rating algorithms granted men credit limits many times higher than women, even when women could demonstrate higher incomes and greater financial assets. Even Apple co-founder Steve Wozniak admitted to this, having been given a 10 times higher limit than his wife, despite their full community of property. Dastin (2022) demonstrated that companies such as Amazon have become victims of their own success. The automation mechanism, built on AI algorithms, which was the foundation of Amazon's market position, was applied to recruitment. Unfortunately, the algorithm favored men and depreciated applications submitted by women. Data bias, manifested in the reproduction of gender stereotypes, is present in popular graphics tools. Popular generative image creation tools, such as DALL-E and Stable Diffusion, when asked to generate images of senior managers (e.g., CEOs), overwhelmingly use images of white men. At the same time, requests to generate images of nurses or cleaners are depicted using women or minorities. Yu et al. (2022) exposed an algorithmic fairness metric that was used by LinkedIn for recruitment recommendations. The algorithm favored men over women with the same qualifications. Fortunately, LinkedIn improved its algorithm.

Healthcare is a key social area where manifestations of racism can be found. Obermeyer et al. (2019) exposed the racist tendencies of the American healthcare system, which uses commercial algorithms to support treatment decisions. The authors showed that the algorithms reduced the chance of black people qualifying for treatment by 50%. The algorithm used the cost of treatment as an indicator of health needs. Lower treatment costs for black people compared to white people meant that the algorithm treated black people as healthier and therefore referred them for additional tests less often. Manifestations of racism can also be found in systems that support the justice system. An example is the COMPAS

[1] https://time.com/5724098/new-york-investigating-goldman-sachs-apple-card/

algorithm, now operating under the name Equivant, created by Northpointe to predict the risk of crime in American courts. A 2016 report by ProPublica[2] found that black defendants were incorrectly assessed as high risk (45%) compared to white defendants (22%). On the other hand, white defendants were significantly underestimated as low risk, despite reoffending. In turn, Buolamwini et al. (2018) published a paper exposing critical data bias in commercial facial recognition systems used by companies such as IBM and Microsoft. The authors showed that the classification error for black women was 34.7%, while for white women it was only 0.8%. Seemingly innocent recommendation environments are also not free from manifestations of racism. A recently published platform for testing hairstyles[3], which was supposed to assess a person's intelligence and professionalism on this basis, rated photos of black women worse. Summarizing the examples documented in literature and reports, one can only imagine how many manifestations of bias in AI data and models can be expected.

## CONCLUSIONS AND IMPLICATIONS

So, the question arises: how can bias be eliminated or prevented? The most obvious way to prevent bias is to ensure diverse and representative data in the model learning process, both in terms of the problem perspective and demographics. Reviewers and editorial committees of journals have a special role to play in this field. Attention to research methodology, appropriate selection and diversification of data sets are among the basic measures that are the responsibility of the scientific community. Being aware of the lack of explainability of contemporary artificial intelligence models, work on broadly understood explainable AI should be intensified. Regardless of this, we can expect a proper discussion and critical reflection on the social implications of the models being developed and the data sets used. We still feel that such critical discussion is insufficient.

However, nothing can replace continuous monitoring to detect emerging biases. In all scenarios that may have ethical or legal implications, it is worth keeping humans in critical decision-making loops. At the same time, for existing AI models, one may not be aware of their biases. In such cases, numerous bias verification tools can be used. Popular tools include: Google's What If-Tool[4], Amazon SageMaker Clarify[5], Fiddler AI[6], IBM AI Fairness 360[7], Microsoft Fairlearn[8] and Credo AI[9]. They use generally accepted fairness metrics, adversarial testing and counterfactual analysis to observe how changes in input data affect AI model predictions. A universal mechanism is model explainability, which should allow for a better understanding of decision-making criteria. With access to decision-making criteria and thresholds, it is always possible to verify how they affect fairness or facilitate informed decision-making.

[2] https://www.propublica.org/article/how-we-analyzed-the-compas-recidivism-algorithm
[3] https://janicejnice.substack.com/p/i-tested-ai-on-different-black-hairstyles
[4] https://pair-code.github.io/what-if-tool/
[5] https://aws.amazon.com/sagemaker/ai/clarify/
[6] https://www.fiddler.ai/
[7] https://research.ibm.com/blog/ai-fairness-360
[8] https://fairlearn.org/
[9] https://www.credo.ai/

However, nothing can replace continuous monitoring to detect emerging biases. Furthermore, in all scenarios that may have ethical or legal implications, it is worth keeping humans in the loop for critical decisions.

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# FOSTERING PLAYFUL LEARNING: ACCESSIBILITY IN EDUCATIONAL GAMES FOR OLDER ADULTS

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Abstract: *Educational games played on mobile devices can be utilized in teaching older adults to foster motivation, create a competitive spirit, and provide playful experiences within the classroom. There has been little previous research on the accessibility of educational games and the playful experiences of older adults. To identify which features facilitate or create potential barriers, this article offers insights into the educational games Kahoot! and Quizizz, focusing on their perceived accessibility and the playful experiences they provide for older adults. 27 participants participated in four distinct gaming sessions. Data was collected through surveys and observational methods. The results highlight issues related to accessibility, such as the pace of the game and classroom space design, including lighting and the size of the classroom display. While older adults found educational games enjoyable, interesting, and novel, the rapid pace of the games led to frustration.*

Keywords: *accessibility, games, gamification, playful experiences, older adults.*


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## INTRODUCTION

There has been a global recognition of the increasing population of older adults and the potential benefits of games in enhancing their well-being and cognitive functions. Various memory games played on tablets enhance short-term memory, while puzzle games improve visual and visuospatial abilities, as stated by Canapa, Paterno, and Santoro (2025). Sertel et al. (2025) explored the benefits of virtual intelligence games on cognitive skills, mood, and quality of life in older adults. The study found that playing smartphone-based games significantly enhanced cognitive functions, including memory, attention, numerical processing, and visuospatial skills. These activities also improved mood, alleviated depressive symptoms. Additionally, the findings revealed associations between sociodemographic factors, mental health, independence in daily activities, quality of life, and social participation.

The results highlight the value of incorporating socially engaging elements into geriatric rehabilitation to support older adults' overall well-being. The relationship between games and older adults' interactions and social relationships has been studied. Nakagomi et al. (2025) explored the impact of digital gaming on the health and well-being of older adults. The results indicated increased social interaction, with older adults' participation in hobby groups and meetings with friends showing an increase. However, the research found that games played on computers, mobile phones, smartphones, tablets, and consoles did not significantly enhance general well-being, including happiness, life satisfaction, and physical and mental health.

Educational mobile and VR games have been used to support older adults' learning, both in community college settings, as studied by Forssell et al. (2023), and in leisure activities for older adults, as described by Forssell, Hassan, and Turunen (2024). The significance of examining the accessibility and playful experiences of educational games among older adults is increasingly recognized, particularly as they engage with diverse platforms. The study by Forssell et al. (2023) and Forssell, Hassan, and Turunen (2024) identified both accessibility barriers and a spectrum of positive and negative playful experiences in this context. A systematic review by Liang and Kuo (2025) highlighted that game-based interventions can effectively motivate and engage older adults in the learning process. In order to fully benefit from educational games for older adults and promote their cognitive skills, social interaction, and learning by ensuring that they have enjoyable and accessible gaming experiences, research into the accessibility and playful experiences of educational games with this target group is essential.

Older adults' use of technology is associated with challenges due to aging. However, barriers can also include cultural background, limited IT skills, and fear or uncertainty about the technology being used, as Bahadori et al. (2025) found in their study. The Bahadori et al. (2025) research identified accessibility challenges that hindered older adults' ability to use technology effectively and consistently. Accessibility issues included small font sizes, bulky mobile devices, insufficient internal memory, and the complexity of using smartphones. According to Bahadori et al. (2025), cultural barriers included a lack of cyberspace culture, while societal barriers encompassed the digital divide and poverty. Older adults face insufficient technological knowledge, limited access to technology, and inadequate IT-education. Barriers due to aging included physical and cognitive limitations such as reduced hand dexterity, sensory impairments.

This article presents a study that examines the accessibility and playful experiences of the popular digital educational games Kahoot! and Quizizz among older adult students. Educational games are employed to support teaching in classrooms, and the accessibility of the entire game session must be considered, including factors such as classroom lighting, screen size, and acoustics.

The survey conducted in the study revealed that older adults had previously engaged with board games such as Mill, Checkers, and Mahjong, as well as entertaining games like Mario Bros, Solitaire, and Angry Birds. Only one participant had prior experience with Kahoot, a digital educational game. Given that digital educational games were novel to the participants, it was well-founded to investigate the topic further.

The study examined the perceptions of older students in classrooms and identified the accessibility needs for these games. Additionally, the research aimed to discern whether older adults have a presumed negative disposition towards digital games. Consequently, the study investigated the playful experiences of older adults with digital educational games. Hence, field experiments were conducted at three different community colleges in Finland through surveys and observations.

The aim was not to specifically study retirement-age students, rather, the participants were active older adults. The study participants were selected based on the community college learning groups intended for older students. Although there was no minimum age limit in the groups, the participants were older due to the nature of the courses. Such a study is essential to understand the potential playful advantages and pitfalls of using educational games with older students, and especially the potential accessibility issues distinctive to this age group.

## Games Accessibility

Despite the increasing popularity of educational games, research on accessibility for older adults remains limited. Forssell, Hassan, and Turunen (2024) highlight that older adults often face barriers such as poor fit of VR headsets and difficulties with game controls, which can hinder their experience with educational games. Additionally, Forssell, Hassan, and Turunen (2024) found that older adults with more experience using smartphones and computers had fewer issues with game controls, suggesting that prior technological familiarity plays a significant role in ease of use.

Moreover, Forssell, Hassan, and Turunen (2024) observed that while educational games have the potential to enrich the lives of older adults, the accessibility of these games is often compromised by design issues that do not account for age-related physical and cognitive limitations. This aligns with the findings of Wang, Hou, and Tsai (2020), who discovered that digital games can improve older adults' cognitive skills and overall well-being, but accessibility remains a crucial factor. Hassan (2024) further emphasizes that the accessibility of games and game-based applications is essential for ensuring that older adults can fully benefit from educational opportunities. Therefore, it is critical to tackle these accessibility challenges to ensure that older adults can fully benefit from these educational games.

Prior research has shown that educational games can significantly enhance learning outcomes by providing immersive and interactive experiences. Forssell, Hassan, and Turunen (2024) emphasize that educational VR games can support teaching by creating engaging and realistic learning environments. These games allow older adults to practice skills in a safe and

controlled setting, which is particularly beneficial for learning complex subjects. The study by Forssell, Hassan, and Turunen (2024) also indicates that educational VR games can increase motivation and interest in learning, as they offer a novel and enjoyable way to engage with educational content.

## Playful experiences

The experiences and feelings of users form the foundation for developing educational games. According to Lucero, Holopainen, Ollila, Suomela, and Karapanos (2013), studying players' experiences and feelings, as well as the elements of games, is essential for understanding why people play and what emotions educational games evoke in users. Examining playful experiences helps to identify which elements in a game are enjoyable for users and motivate them to continue playing. Different dimensions of the game provide motivation for users; for instance, some may find the element of competitiveness central, while others may require narrative features. However, these experiences are not necessarily static and may evolve over time. It is therefore essential to investigate factors that hinder gameplay, such as feelings of frustration. Lucero et al. (2013) also underscore the importance of examining such negative experiences that can act as barriers to engagement. Furthermore, Kiili, Siuko, Cloude, and Dindar (2023) suggest intrinsic integration can be linked to playful cognitive engagement and game-based content.

When studying playful experiences in older adults, these experiences may be negatively influenced by physiological differences compared to younger age groups. According to Anttila (2023), these differences can include slower hand-eye coordination, reaction ability, or deteriorated vision. Older adults' independent use of devices can be hindered by the decline of memory, fine motor skills, sensory muscle condition, and exercise ability. Consequently, this may lead to unsuccessful interactions with educational games on mobile devices or computers, eliciting negative emotional responses such as frustration. Forssell et al. (2023) highlight that older adults experienced a range of playful emotions during VR gaming sessions, including confusion, fear, thrill, excitement, interest, curiosity, and enjoyment. These playful experiences can enhance engagement and motivation, making educational games not only informative but also enjoyable for older adults.

## Educational Games

According to Pereira et al. (2021), educational games, also known as serious games or game-based learning tools, are designed to fulfill pedagogical objectives by embedding educational content within interactive and engaging gameplay. These tools aim to foster motivation, engagement, and knowledge retention by transforming conventional learning experiences into dynamic and enjoyable ones. Pereira et al. (2021) demonstrated that integrating educational material into a citizen science game, particularly through gradual content access as a reward for progression, significantly enhanced player engagement, retention, and performance. However, the effectiveness of such games is not without challenges. According to Fernández Galeote et al. (2022), one of the central challenges in designing educational games is finding a balance between delivering structured learning content and allowing players the freedom to explore and make autonomous choices. If games are designed too rigidly or are overly focused

on instruction, they risk reducing player engagement and limiting the effectiveness of the learning experience. As Fernández Galeote et al. (2022) emphasize, meaningful game-based learning requires careful attention to player agency, allowing for playful interactions, divergence from prescribed paths, and emotional engagement. These findings by Fernández Galeote et al. (2022) underscore the importance of designing educational games that not only convey content effectively but also respect and support diverse player experiences and motivations. By Sailer and Homner (2019), although gamification has been shown to positively influence cognitive, motivational, and behavioral learning outcomes, its effectiveness depends heavily on design quality and contextual factors. Sailer and Homner (2019) highlight that while gamification can enhance motivation, it may also produce mixed results, particularly in terms of sustained engagement. Furthermore, most empirical studies included in their meta-analysis focus on younger learners, especially in higher education settings, indicating a lack of research on how older adults experience and benefit from gamified learning environments. A systematic review by Koivisto and Malik (2021) highlighted this gap, emphasizing the need for more studies on gamification among older adults. Their findings suggest that while gamified interventions in health education and human-computer interaction contexts show promise, such as increased physical activity and improved self-efficacy, the evidence remains preliminary due to small sample sizes and methodological limitations.

## Educational Game Design for Digital Inclusion of Older Adults

Although educational games hold significant promise for enhancing the lives of active older adults, their design must be firmly grounded in accessibility principles and responsive to the distinct challenges associated with aging. In the absence of such considerations, digital learning environments risk perpetuating digital exclusion rather than fostering inclusive and engaging learning experiences. Hence, in designing educational games for older adults, it is essential to consider age-related changes in sensory, cognitive, and motor functions. As Forssell, Hassan, and Turunen (2024) note, older individuals often face challenges related to vision, hearing, and hand dexterity, which can significantly affect their ability to interact with digital interfaces. These limitations are further compounded by limited prior experience with digital technologies, making the learning curve steeper and potentially discouraging.

In addition to these physiological and experiential factors, research on older adults' use of digital health services in Finland highlights broader usability and accessibility challenges in the use of novel technology. According to Vehko, Ruotsalainen, and Hyppönen (2019), many older users report difficulties with unclear instructions, fear of making mistakes, and a lack of support when using digital services. These findings underscore the importance of designing educational games that are not only technically accessible but also cognitively and emotionally.

Games that rely on fast-paced interaction, complex navigation, or small interface elements may unintentionally exclude older adults, particularly those with reduced fine motor skills or slower reaction times. As Forssell, Hassan, and Turunen (2024) found, such design features in VR games can hinder accessibility and limit the enjoyment and learning potential for older users. In addition, Forssell, Hassan, and Turunen (2024) noted the absence of intuitive controls and insufficient visual or auditory feedback were identified as key barriers to engagement, emphasizing the need for inclusive design that supports diverse sensory and cognitive needs

The Finnish digital inclusion strategy by Vehko, Ruotsalainen, and Hyppönen (2019), as reflected in the national eHealth survey, emphasizes that digital services must be perceivable, operable, understandable, and robust principles that are equally vital in designing educational games for older adults. The Vanhus- ja lähimmäispalvelun liitto VALLI ry. The (2023) report and the Digi arkeen -neuvottelukunta (2019) report both stress the need for simplicity, clarity, and adaptability in digital solutions for older adults. These principles translate into game design as well, such as interfaces should offer adjustable text sizes, voice guidance, and simplified navigation paths. Importantly, involving older adults directly in the co-design process can ensure that the resulting games reflect their needs, preferences, and lived experiences.

## METHODS

To address the research questions, what accessibility challenges older adults encounter when using digital educational games, how they perceive and experience playfulness during gameplay, how intuitive these games are without prior instruction, and how physical classroom environments influence their experiences, a series of user studies were conducted from the fall of 2021 to the spring of 2022 at community colleges in the municipalities of Sastamala, Valkeakoski, and Vanajavesi in Finland. The participating community colleges aimed to develop innovative teaching methods by integrating gamification elements into existing courses for older students. This initiative sought to familiarize learners with interactive technologies and reduce the barriers that often hinder older adults from adopting new digital education technology.

The pedagogical framework employed in this study was grounded in experiential learning, with a focus on adult and older learners. Approaches that emphasize lifelong learning and draw upon individuals' personal and professional histories were particularly well-suited for this research context. Older students bring a diverse range of skills acquired over their lifetimes, which influence how they approach unfamiliar situations and engage with new technologies.

To explore this dynamic, participants were not provided with instructions at the outset of the game sessions. Instead, the study aimed to observe how they navigated the challenges independently, relying on their accumulated life experience. Kolb's (2014) theory of experiential learning, which conceptualizes education as a continuous, cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation, served as a foundational model for this investigation.

As emphasized by Kleinheksel et al. (2023), the theory conceptualizes learning as a cyclical progression through concrete experience, reflective observation, abstract conceptualization, and active experimentation. This model highlights the integration of experience and reflection as essential to meaningful learning, reinforcing the connection between theoretical knowledge and practical application across educational and professional contexts. Using these pedagogical approaches in this study helps to observe and guide the development of older adults and adult students' technological understanding.

As a component of the teaching strategy, a series of short lessons titled "Threats on the Web: Be Safe in Cyberspace" was developed for community college lectures, aiming to educate older students about cybersecurity threats. The instructional design was structured in two parts. In the first part, students viewed a brief video tutorial on cybersecurity at the beginning of the lecture, followed by a guided discussion that expanded on the topics presented

in the video. In the second part, the content was revisited through the use of an educational game, either Kahoot! or Quizizz, which served as the focal point of this research.

A total of four field experiments were conducted: two utilizing Kahoot! (in Sastamala and Valkeakoski) and two utilizing Quizizz (in Valkeakoski and Vanajavesi). The overarching aim of both the instructional sessions and the research was to identify potential accessibility challenges encountered by older adults when engaging with educational games. Additionally, to examine how they respond to and resolve such challenges during gameplay. Field experiments were selected as the methodological approach to ensure that the introduction of educational games occurred within authentic classroom environments, thereby enhancing validity and avoiding the limitations of artificial settings. A mixed-methods approach was employed to capture a comprehensive understanding of participants' experiences. Surveys and interviews were used to access participants' subjective reflections and perceptions, while observational methods complemented these tools by capturing behavioral responses and contextual factors that participants might not have been able to articulate explicitly.

## Game Mechanics and Flow

Data collection took place in classrooms that were regularly used for the education of older adult learners, ensuring that the study was conducted in familiar and authentic learning environments. Participants were not assigned specific seats, as the intention was to observe whether their seating choices or behaviors changed once the game sessions commenced. Additionally, the study aimed to capture whether participants would verbalize any difficulties related to the physical environment, such as visibility, acoustics, or spatial arrangement, and how they attempted to address or adapt to these challenges as the game session progressed.

The instructional approach deliberately minimized the explanation of game rules and mobile phone controls prior to gameplay. This was intended to assess the intuitiveness of the game mechanics and to observe how older adults navigated the experience using their existing knowledge and life skills. When the first question appeared on the screen, several participants expressed confusion regarding how to proceed in the game. In response, the game was temporarily paused, and the researcher provided a brief overview of the gameplay structure and rules. The first question functioned as a training round, designed to familiarize participants with the game format. By the second question, most students appeared to engage more confidently and demonstrated an understanding of the game's mechanics. This approach aimed to evaluate the extent to which the games were intuitive, defined, following Kolb (2014), as the ability to interact with new tools or environments without explicit instruction, drawing on prior experiences. Although some participants expressed interest in replaying the game or having a rematch, each educational game session was conducted only once during the field experiments.

The Kahoot! and Quizizz game sessions were deliberately structured at a slow and accommodating pace to allow for potential interruptions, discussions, and technical difficulties. Although the actual gameplay lasted approximately four and a half minutes, the entire session spanned 30 to 40 minutes. Time was allocated at the beginning of each session for participants to log into the game, with potential login difficulties anticipated and incorporated into the session planning. Additionally, time was reserved at the end of each session for a debriefing discussion and for reviewing the game results. The questions presented at the games were

directly related to the content of the preceding lecture, thereby reinforcing learning through interactive engagement.

Each Quizizz session consisted of nine questions, with older adults selecting between one correct and one incorrect answer option. A 30-second time limit was allocated for each question. While the core gameplay lasted approximately eight to twelve minutes, the overall duration varied depending on the need for additional instructions following the initial round of questions. In some instances, participants paused to discuss the content or to celebrate correct responses, which extended the session length. In Quizizz, both the questions and answer options were displayed on the classroom screen as well as on each participant's device. However, in Kahoot! the questions were presented on the shared classroom screen, while the answer options, represented by colored symbols, were visible only on the participants' individual devices (see Figure 1).

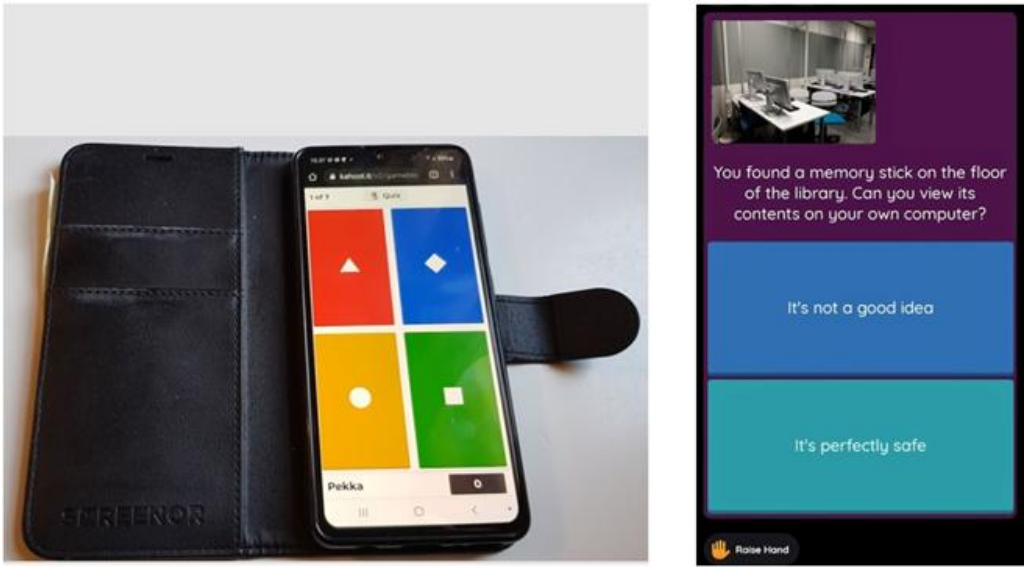


**Figure 1.** Kahoot! and Quizizz game interface on a smartphone. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Each Kahoot! game session consisted of nine questions, with four answer options provided for each. The game was designed such that some questions had a single correct answer, while others included two correct options. This required participants to discern the number of correct responses without prior instruction, as this detail was not communicated at the outset. However, clarification was provided during the session if participants inquired about the number of correct answers. In Kahoot!, the questions were displayed on the classroom screen, while the answer options appeared as four distinct colored symbols on each participant's device, whether played with a smartphone, tablet, or computer (see Figure 1).

## Kahoot! and Quizizz

Kahoot! and Quizizz was selected for this study due to the primary researcher's prior experience using these platforms in teaching older adults in community college and vocational education settings. Observed accessibility challenges in these contexts served as a motivating

factor for initiating the present research. Both Kahoot! and Quizizz are widely used, internationally recognized educational tools that share similar design principles, yet differ in specific features that may influence their accessibility. For the purposes of this study, both platforms were deemed sufficiently intuitive and user-friendly, minimizing the risk of inducing technology-related anxiety among older adult participants. Their simplicity also facilitated a smoother transition into discussions about participants' perceptions and experiences with educational games.

Kahoot! is a widely adopted game-based learning platform that can be accessed via mobile devices, tablets, computers, or any internet browser through www.kahoot.it. While the basic version is freely available, additional features can be accessed through paid licenses. The platform follows a quiz-style format, presenting one question at a time with four answer options. Questions are displayed on a shared screen, while participants respond using their personal devices (see Figure 1). Typically, Kahoot! game sessions include a time limit and a live leaderboard, which fosters competition and enhances engagement. Recent research has demonstrated Kahoot!'s effectiveness in educational contexts. A recent study by Navarro-Castillo, Pablo-Lerchundi, and Morales-Alonso (2025) demonstrated that the use of Kahoot! significantly enhanced learning outcomes for engineering students in economics and management courses. The study highlighted the platform's effectiveness in increasing student motivation, participation, and knowledge retention, reinforcing its value as a pedagogical tool in higher education.

Quizizz is a widely used game-based learning platform that allows educators to create and deliver interactive quizzes via mobile devices, tablets, or computers through www.quizizz.com. Unlike some other platforms, Quizizz offers greater flexibility in game formats and instructional features. For instance, it supports both "instructor-paced" mode, where participants progress together, and "classic" mode that allows learners to advance at their pace. These options make it adaptable to various teaching contexts and students' needs. Recent research by Hernanz et al. (2024) demonstrated that the use of Quizizz significantly enhanced students' self-efficacy, intrinsic motivation, satisfaction, and academic performance across multiple university programs. The research highlighted the platform's effectiveness in fostering active participation, and improving learning outcomes. Additionally, in educational settings that emphasize student engagement and interactivity. Both Kahoot! and Quizizz can be considered easy access platform for gamification in education, providing meaningful pedagogical value when thoughtfully integrated into instructional design.

## Participants

Participants were recruited from three community colleges participating in the study to take part in both the "Threats on the Web: Be Safe in Cyberspace" lecture and the associated research activities. Participation was entirely voluntary and had no impact on students' performance or course evaluations. Informed written consent was obtained from all participants, outlining the research procedures, ethical considerations, and ensuring anonymity. A total of 27 students participated in the study. Of these, 21 were from Valkeakoski and Vanajavesi Community Colleges and completed a demographic survey. Their age distribution was as follows: 6% were aged 41–50, 12% were 51–60, 38% were 61–70, 31% were 71–80, and 13% were 81–90 years old. Notably, 82% of participants were over the age of 61. At

Sastamala Community College, age data were collected informally through verbal inquiry, with the six participants estimated to be between 60 and 80 years old.

## Data collection

Both observational and survey data were collected during the field experiments (Vilkka 2025). The purpose of the observational data was to assess the accessibility of the physical learning environment and its influence on gameplay. Specific factors examined included the students' distance from the blackboard, classroom lighting conditions, screen or board reflectivity, and acoustics. Observations also focused on how participants responded to environmental challenges during gameplay, including whether and how they verbalized difficulties and the strategies they employed to address them.

Observational data were recorded in field diaries during and immediately after each session. To complement these observations, a survey was administered in Finnish, based on a modified and abbreviated version of the Playful Experiences (PLEX) framework. Originally developed by Korhonen, Montola, and Arrasvuori (2009), the PLEX framework is designed to capture a broad spectrum of emotional and experiential responses to playful systems and has been widely applied in user experience and game-based learning research.

Participants were invited to select from a list of predefined experiential descriptors to characterize their feelings during gameplay. These included: accomplishment, challenge, communality, competition, concentration, deviation from traditional teaching, empathy, excitement, frustration, humor, imagination, inspiration, mastery, novelty, relaxation, stimulation, self-expression, and unpleasantness. To gain more profound insight into these experiences, participants were also asked to provide open-ended responses describing their gameplay experience in their words.

The qualitative responses were analyzed using the affinity diagram method, a technique used to externalize and organize unstructured qualitative data into meaningful thematic clusters by Lucero (2015). According to Schrader, (2022), this method is particularly effective for identifying emergent patterns in user experience research and has been validated in the context of serious games and game-based learning.

Older adults were provided with key information regarding the information security aspects of the game prior to participation, and privacy notices were presented. They were informed that accessing the game did not require downloading any applications onto their personal devices, nor did it necessitate logging in or sharing personal data. Additionally, participants were advised that they could use a first name, nickname, or any pseudonym of their choice when joining the game, thereby ensuring anonymity and minimizing privacy concerns.

# RESULTS

The following sections present the results of the study. First, findings concerning the accessibility of Kahoot! are discussed. This is followed by an analysis of the accessibility of the educational game Quizizz. Subsequently, the results related to the playful experiences

associated with both platforms are examined. The section ends with the study's limitations and suggestions for future research.

## Accessibility of Kahoot!

At Sastamala Community College, six students aged between 60 and 80 years participated in the study. The participants utilized their smartphones as controllers to engage with the educational game platform Kahoot (see Figure 1). At the outset of the session, participants were asked whether they had prior experience with digital games; only one individual indicated previous engagement. None of the participants had used Kahoot before. Upon initiation of the game, several students moved closer to the projection screen (see Figure 2), with one participant commenting aloud that the questions were difficult to read.

**Figure 2.** The white canvas, rolled up on the right side of the chalkboard, was used during the gaming session at Sastamala Community College. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Although the same canvas had been used in previous classes without issue, this feedback suggests that the game interface may have featured smaller-than-average font sizes or insufficient contrast. When the first question appeared, the students expressed confusion regarding the gameplay mechanics. Consequently, the session was paused to provide a brief explanation. The initial question had been designed as a practice round. By the second question, participants began to understand the format and became actively engaged. They displayed enthusiasm, initiated friendly competition, and encouraged one another to improve their performance.

One of the most frequently identified accessibility challenges was the game's pace. Despite extending the response time to 30 seconds (from the default 20 seconds), nearly all participants reported that the game progressed too quickly. At Valkeakoski Community College, seven students participated in the study, although only one completed the post-session survey. Four participants used their smartphones as game controllers, while two others shared a tablet. Once the game commenced, students reported difficulty seeing the questions and answer options due to the small screen size (see Figure 3).

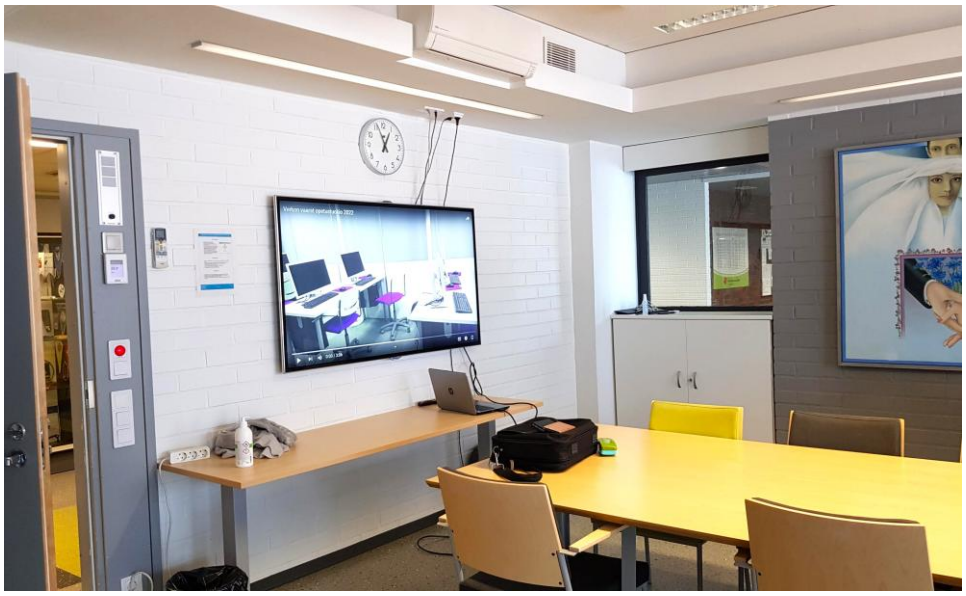

**Figure 3.** Classroom display used during a Kahoot! game session at Valkeakoski Community College. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Although they were encouraged to move closer, none opted to change seats. Consequently, the facilitator had to read the questions and answer choices aloud to ensure the session could proceed. During the game session, one participant expressed difficulty understanding the overall concept of the game. Several others struggled to respond within the allotted 30 seconds. Participants also noted that the game moved too quickly, the font size was too small, logging in was challenging due to the interface being in a foreign language, and the game rules were not easily comprehensible. Despite these accessibility barriers, the session was not without positive feedback. One student remarked enthusiastically during gameplay, “My heart rate rises while playing this game.” In the open-ended responses, participants described the session as interesting, enjoyable, and beneficial in supporting the lesson content.

## Accessibility of Quizizz

In a subsequent session at Valkeakoski Community College, the educational game platform Quizizz was employed. One student participated using a smartphone, while the remaining seven used desktop computers. All Quizizz sessions were conducted in instructor-paced mode. Logging into the game posed challenges for all participants, primarily due to the platform being in English, a foreign language for the students, and the complexity of the web address, which was prone to typing errors. Notably, one participant inadvertently accessed a fraudulent website designed to mimic the official Quizizz platform.

At the start of the session, three students expressed enthusiasm about using a game to review previously learned material. However, some voiced concerns, asking questions such as, “Am I able to play this game? Is it too hard?” As the game progressed, two students reported that the 30-second response time felt too short, and that screen visibility was impaired due to glare. To address this, the classroom lights were turned off and Quizizz’s dark mode was enabled, which improved visibility (see Figure 4.).

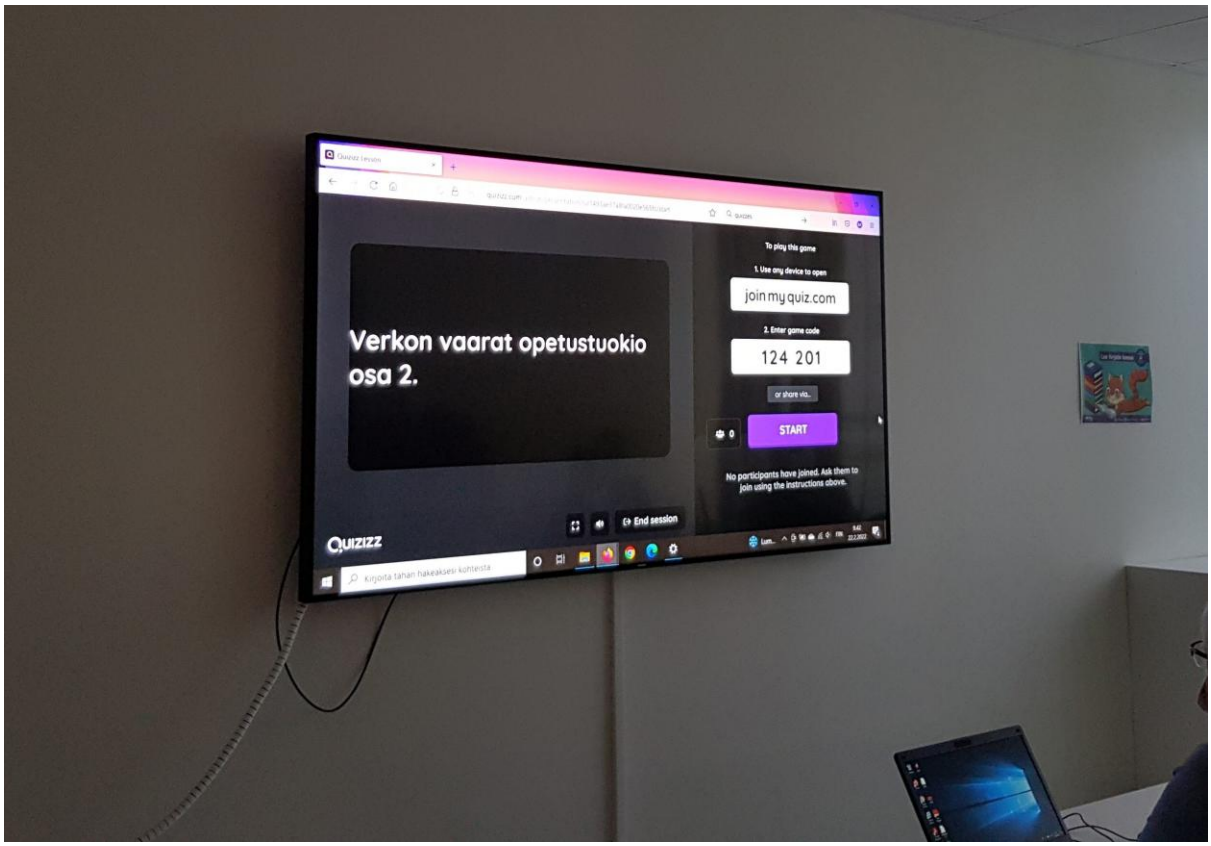


**Figure 4.** Classroom display used during a Quizizz game session at Valkeakoski Community College. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Following the game session, students were given a revised survey. This version was adapted based on insights from the earlier Sastamala session, with simplified language to enhance clarity, and additional multiple-choice and open-ended questions to gather more detailed feedback on accessibility and participants' gaming backgrounds. In the open-ended responses, students described the experience as interesting, enjoyable, and novel. Nevertheless, they reiterated that the game's pace was too fast. While the difficulty level was deemed appropriate, logging into the game remained the most challenging aspect.

Regarding prior gaming experience, three of the eight participants had never played digital games. Among the rest, four had used computers, three had used smartphones, game consoles, and board games, and two had experience with tablets. The limited gaming experience was largely attributed to a lack of interest. In response to the question, "Have you experienced any problems while gaming? For example, the game is in a foreign language, the rules are difficult to understand, or the font size is too small," one student noted, "Games have been easy, but usually logging in is the hardest part." Another reported difficulties with foreign language use and understanding game rules.

In the final session, held at Vanajavesi, six students participated, all using desktop computers. As in previous sessions, all participants encountered difficulties logging into the Quizizz platform. Once the game began, students again reported that the questions appeared too quickly. It took several questions for participants to become familiar with the gameplay.

As the session progressed, the atmosphere became increasingly positive. Students celebrated their successes, with the game winner expressing excitement and others applauding enthusiastically at the end. The physical classroom environment was considered well-suited for older adult learners. Hence, the screen was large, the lighting was adequate, and no issues with visibility were reported (see Figure 5.).


**Figure 5.** Classroom display used during a Quizizz game session at Vanajavesi Community College. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Survey responses indicated that four of the six participants had not previously played digital games. Two had experience with phones, tablets, computers, and game consoles, while three had played board games. Overall, participants reported that they rarely engaged in gaming and generally lacked interest due to limited prior experience. Despite this, they described the session as a pleasant and positive learning experience.

## Accessibility Adaptations in Game Sessions

To accommodate the cognitive and perceptual needs of older adults, several accessibility adaptations were implemented during the game sessions. In both Kahoot! and Quizizz, the response time for each question was set to 30 seconds to reduce time pressure and allow participants more time to reflect. In Kahoot!, this meant extending the default time from 20 seconds. In Quizizz, although the default time was not explicitly stated, the 30-second limit was consistently applied across sessions. Additionally, in Quizizz, the classroom lights were turned off and dark mode was enabled to improve screen contrast and reduce glare (see Figures 6. and 7.).

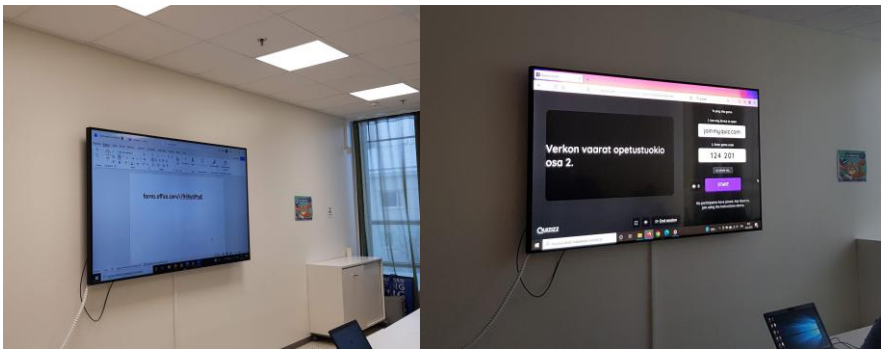


**Figure 6. and 7.** Classroom lights were turned off and dark mode was enabled to improve screen contrast and reduce glare during a Quizizz game session at Valkeakoski Community College. [Source: Forssell, Hassan, Turunen & Aura, 2023]

Questions in both games were designed to be directly related to the lecture content and kept simple to avoid unnecessary complexity. The first question in Kahoot! was used as a training round, and verbal instructions were provided to clarify the game mechanics. Despite these efforts, some participants still reported challenges with font size, screen visibility, and understanding the number of correct answers, indicating that further customization of game interfaces may be necessary to fully support accessibility for older users.

## Playful Experiences

This study employed two complementary research methods to gain a comprehensive understanding of older adults' playful experiences during educational game sessions designed to support teaching and learning. Open-ended responses were analyzed using the Affinity Diagram method (Lucero 2015), which revealed six distinct categories of playful experience: enjoyment, interest, novelty, frustration, confusion, and anxiety. Enjoyment was the most frequently reported experience, with seven participants expressing positive sentiments toward the educational game. Interest was articulated by five participants. Both novelty and frustration were mentioned three times. Frustration was primarily associated with the fast pace of the game, which several participants found challenging. Confusion and anxiety were each mentioned twice. Confusion stemmed from difficulties in understanding the game mechanics and rules, while anxiety was linked to the competitive nature of the game. One participant, for

example, reported feeling anxious because the game reminded them of a school pop quiz. A summary of the frequency of each reported experience is presented below (see Table 1.).

**Table 1.** Emotions from open answers using an affinity diagram.

| Type | Emotions |
|---|---|
| Enjoyment | 7 |
| Interest | 5 |
| Novelty | 3 |
| Frustration | 3 |
| Confusion | 2 |
| Anxiety | 2 |

The results, analyzed using the PLEX (Playful Experiences) Framework, revealed a diverse range of playful experiences reported by older adult participants. According to ten respondents, the gaming experience differed notably from traditional classroom instruction, with novelty being selected eight times. Participants most frequently reported experiences of excitement, concentration, accomplishment, and competition, each mentioned seven times. Relaxation and inspiration were each selected five times, while mastery, communality, and humor were each chosen four times. Empathy was reported three times, and frustration, rousing, and challenge were each selected twice. Imagination was mentioned once. Notably, none of the participants selected self-expression or unpleasantness as part of their experience. A detailed breakdown of the frequency of each playful experience is presented in (see Table 2).

**Table 2.** PLEX framework.

| Type | Emotions |
|---|---|
| Different from normal teaching | 10 |
| Novelty | 8 |
| Excitement | 7 |
| Concentration | 7 |
| Accomplishment | 7 |
| Competition | 7 |
| Relaxation | 5 |
| Inspiring | 5 |
| Mastery | 4 |
| Communality | 4 |
| Humour | 4 |
| Empathy | 3 |
| Frustration | 2 |
| Rousing | 2 |
| Challenge | 2 |
| Imaginative | 1 |
| Self-expressive | 0 |
| Unpleasantness | 0 |

## Limitations

As with any research, this study has certain limitations. First, it employed a combination of observational and survey data, each with inherent methodological constraints. Observations are subject to the researcher's interpretation, and significant events may be inadvertently overlooked. Surveys, on the other hand, rely on self-reported data, which can be prone to misunderstanding or bias. As Vilkka (2025) notes, observational data can be influenced by the subjectivity of the observer, and the reliability of survey responses may be affected by the participants' interpretations of the questions.

Second, the participants were self-selected, which may have introduced a bias toward individuals with a more favorable disposition toward technology and learning. Third, the sample size (N=27) was modest and limits generalizability, the study was designed as an exploratory field experiment to uncover accessibility and experiential patterns among older adults in authentic learning environments. The diversity in participants' technological backgrounds and attitudes reflects the heterogeneity of the older adult population, which is essential for understanding the range of accessibility challenges and playful responses. However, this is consistent with the qualitative research design employed in the study and was mitigated by conducting four field experiments across three different municipalities in Finland. Forth, although the study did not measure learning outcomes quantitatively, the educational process was implemented through a structured pedagogical framework. Each game session was preceded by a cybersecurity-themed lecture and followed by gameplay that reinforced the lecture content. Participants' reflections were collected via surveys and open-ended responses, which captured both emotional and cognitive engagement.

## Future research

In addition to the positive outcomes observed in recent studies on gamified learning (e.g., Liang & Kuo, 2025) , participants in this study also demonstrated feelings of competitiveness during gameplay. While competition is frequently associated with increased motivation and engagement, its role in educational contexts, particularly among older adults, remains unclear. Educational environments have traditionally favored cooperative approaches, as competition may induce stress or reduce inclusivity. However, a meta-analysis by Sailer and Homner (2020) found that combining competition with collaboration in gamified learning environments can positively influence behavioral and motivational learning outcomes. The emergence of competitiveness as a motivating factor among older adults in this study highlights its potential as a design element in short-term educational game activities. Observational data and participant comments revealed that features such as live leaderboards in Kahoot! and score-based feedback in Quizizz introduced competition that elicited excitement and motivation, but also anxiety in some cases, particularly when the gameplay pace was perceived as too fast or reminiscent of formal testing environments. These findings suggest that competition can serve as a meaningful design element in educational games for older adults, provided it is implemented with careful attention to pacing, emotional comfort, and inclusivity. Moreover, the findings indicate that the fast pace of gameplay can lead to frustration, which may hinder learning. This underscores the importance of designing games that are sensitive to the cognitive and perceptual needs of older users. Future research should aim to deepen the understanding

of older adults' playful experiences by employing larger and more diverse participant samples and incorporating comprehensive emotional and physiological assessment methods. Additionally, further investigation is needed to explore how different game mechanics, such as competition and pacing, affect engagement, emotional response, and learning outcomes among older adults. Such research would contribute to the development of inclusive and age-sensitive game-based learning environments that support both enjoyment and educational outcomes.

## DISCUSSION

This study aimed to explore how older students experience digital games as a pedagogical tool and to examine the accessibility and playful dimensions of two widely used educational platforms: *Kahoot!* and *Quizizz*. The findings suggest that educational games can effectively support teaching among older learners, provided that careful attention is given to the overall accessibility of the experience. Furthermore, the use of such games appears to lower the barrier for older adults to engage with new technologies, as it offers them opportunities to interact with their own digital devices in a familiar and low-pressure environment. Overall, incorporating educational games into classroom activities was perceived as a novel and positive experience by the participants. They reported a range of playful experiences, including excitement, novelty, enjoyment, a sense of control, social connectedness, and accomplishment—attributes that were particularly associated with the use of *Kahoot!* and *Quizizz*.

From an accessibility perspective, several key challenges emerged, including the suitability of the learning environment for gameplay, difficulties logging into the platforms, the use of non-native language in the games, and the overall pace of gameplay. Participants frequently reported that the games progressed too quickly, and the size of the projected display (canvas or display) negatively affected their ability to engage with the content. These issues significantly hindered the overall playful experience. It was also observed that the game mechanics were not intuitive for all older adults, particularly those with limited prior exposure to digital games. While some participants required ongoing guidance throughout the session, others approached the games with curiosity, experimenting independently to understand the mechanics.

The findings suggest that effectively integrating games into educational settings for older adults, and by extension, for individuals with disabilities, requires more than simply designing engaging or gamified content. It necessitates creating inclusive opportunities for participation, exploration, and learning. Through the use of thoughtful pedagogical strategies, minor design modifications, patience, and active instructor support, older adults were able to experience the educational potential of games in a meaningful way. Importantly, the study challenges the assumption that older adults' difficulties with games stem primarily from cognitive limitations or technological illiteracy. The barriers encountered by participants, such as small font sizes, strict time limits, and general accessibility shortcomings, were more significant than the complexity of the game mechanics themselves.

This study contributes to a more profound understanding of the needs and preferences of older adults in the context of educational gaming, offering valuable insights for the development of more accessible and inclusive game designs. Accessibility should not be treated as an afterthought, but must be integrated into the design process from the outset.

Ideally, this process should involve a diverse group of users, including older adults and individuals with varying abilities, to ensure that accessibility considerations are grounded in real-world needs and experiences.

Accessibility in game design is increasingly recognized not merely as a technical requirement, but as a foundational design principle that ensures equitable participation and usability for a diverse range of users. As Aguado-Delgado et al. (2020) emphasize, accessibility in video games remains underdeveloped despite growing awareness. They argue for the adoption of integrated methodologies that embed accessibility throughout the software development lifecycle. Their systematic review highlights a persistent gap between accessibility guidelines and their practical implementation, particularly in games designed for older adults and individuals with disabilities. This perspective aligns with broader trends in inclusive design, which advocate for user-centered approaches that extend beyond regulatory compliance to foster meaningful and empowering user experiences. In this context, accessibility is not an afterthought but a core design ethos that benefits all users, especially those with age-related or sensory limitations.

To contextualize these findings and acknowledge the limitations of the study, it is important to note that this research presents promising insights into the use of educational games with older adults, it is important to acknowledge the exploratory nature of the research. The statements regarding the pedagogical value of educational games, their potential to lower the threshold for engaging with new technologies, and the positive and novel experiences reported by participants are supported by qualitative data, including survey responses and open-ended feedback. Notably, enjoyment was the most frequently reported emotion, and novelty was highlighted both in open responses and through the PLEX framework, indicating that participants perceived the activities as distinctly different from traditional classroom instruction. These findings suggest that educational games can offer meaningful and engaging experiences for older adults. However, the results are based on a limited sample size and do not include quantitative measures of learning outcomes. Therefore, the conclusions should be interpreted as indicative rather than definitive. Further research with larger and more diverse participant groups is needed to validate and generalize these observations.

Finally, it is essential to acknowledge the ongoing transformation within the contemporary gaming industry. As noted by Kinnunen, Taskinen, and Mäyrä (2020), the demographic composition of players is becoming increasingly diverse, with notable growth among female gamers and individuals across a wide spectrum of ages and abilities. This expanding heterogeneity underscores the need for game developers to adopt innovative design strategies and inclusive development practices that address the varied needs, preferences, and capabilities of a broader user base.

## CONCLUSIONS

This study examined the accessibility of educational games, specifically Quizizz and Kahoot!, among older adult learners. The research involved four field experiments conducted at community colleges in Finland, with data collected through structured observations and survey questionnaires. The findings indicate that educational games can effectively support instructional practices for older students, provided that the accessibility of the gaming

experience is carefully considered. Older adults generally perceived the games as enjoyable, engaging, novel, and stimulating. However, a fast-paced gameplay environment was identified as a significant barrier, often leading to frustration and reduced enjoyment.

Key accessibility challenges included difficulties with logging into the game, insufficient font size and contrast, the absence of voice-over features, and the use of non-native languages in the game interface. To improve usability, the study recommends the use of QR codes or shortened URLs to simplify the login process. Additionally, physical classroom conditions, such as lighting, screen size, and the visibility of the display board, were found to play a crucial role in facilitating accessible gaming sessions. Overall, the study emphasizes the importance of addressing both psychological and physiological factors when designing educational gaming experiences for older adults. Addressing these factors can help foster positive learning experiences with digital tools and mitigate potential anxieties or insecurities associated with technology use.

## IMPLICATIONS FOR APPLICATION

The findings of this study suggest that digital games can serve as effective tools for lowering the threshold to adopting new technologies, such as mobile devices, among older adults. To maximize the potential of such interventions, both psychological and physiological factors must be considered in the design of accessible game-based learning environments. These considerations are essential for fostering positive user experiences and addressing common fears or insecurities associated with digital technology use. When accessibility is prioritized and game content is structured to elicit positive emotional responses while minimizing frustration, gamified approaches can function as valuable educational tools. They can support older adults in becoming more comfortable with digital technologies that are increasingly integral to everyday life. Looking ahead, it is imperative to ensure that all individuals remain active participants in an increasingly digitized society. This requires the development of inclusive pedagogical strategies that not only familiarize older adults with emerging technologies but also promote lifelong learning and digital confidence.

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## Authors' Note

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# DIGITAL COMPETENCES OF UNIVERSITY GRADUATES: IMPLICATIONS FOR CAREER SUCCESS

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Abstract: *The role of university graduates' digital competences in their professional careers was analyzed using the Digital Competence Framework for Citizen 2.2. The study was conducted in Ukraine, where a siginificant share of employment during the war is remote (or at least hybrid), requiring the posession and continuous improvement of digital competences. The results are based on a sociological survey of 397 graduates under the age of 35 with professional experience ranging from one year to more than ten years in labor market. To understand career success, respondents were divided into groups: employees in non-managerial positions, middle managers, top managers, and unemployed. The analysis revealed that university education has a significant impact on the formation of digital competences – greater progress occurs during university studies rather than at workplaces. Higher career success (top management positions) is characteristic of respondents with better-developed digital competences, particularly in digital data management, information evaluation, digital communication, and creative use of technology..*

Keywords: *digital competences, DigComp 2.2, employment, university graduates, career success.*


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## INTRODUCTION

In the era of rapid technological development, digital competences have become an indispensable component of employability across nearly all spheres of human activity. The shortage of digital skills and the urgent need for their development remain key challenges in shaping professional competences. At the European Union (EU) level, this has been formaly recognized in Decision 2023/936, which designated the period from 9 May 2023 to 8 May 2024 as the European Year of Skills (EUR-Lex, 2023). According to recent assessments (European Union, 2025), the deficit of transversal competences – among which digital competence plays a pivotal role – is particularly crucial. Digital competence not only has a direct impact, for example through communication but also an indirect one, by fostering critical and innovative thinking, interpersonal and intrapersonal skills, and global citizenship). The European labor market is already experiencing profound transformations due to digitalization and artificial intelligence (AI). Current projections suggest that 32% of jobs may undergo substantial changes due to AI, while 24.5% of candidates lack transversal competences, particularly those relevant to the green and digital transitions. The impact is especially pronounced on small and medium-sized enterprises (SMEs), where 62% report an urgent need for stronger digital competences (European Union, 2025).

Against this backdrop, universities and the labor market often face a structural skill gap. The pace of technological change outstrips universities' capacity to adapt curricula, resulting in a mismatch between the digital competences acquired during studies and those required in professional environmens. This problem has been widely acknowledged in both academic and applied research. In the meantime, digital competences offer significant professional advantages, enhancing productivity (Hadiansyah et al., 2024; Saeful & Ekhsan, 2024), employability (Avram et al., 2021; Iwashita et al., 2021; Wang et al., 2023), and ultimately, individual benefits in terms of higher income and competitivemness.

In accordance with the Recommendation of the European Parliament and of the Council of 2006 and 2018, *digital competence* was recognized as one of the key competences for lifelong learning (European Commission, 2006; European Commission, 2018), and in 2020 it was classified as a basic skill necessary for ensuring sustainable development and social justice (European Commission, 2020).

In the Council Recommendation on key competences for lifelong learning, *digital competence* is defined as the one that "involves the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society" (European Commission, 2018). According to the European Training Foundation, "digital competence referred to as digital literacy, encompasses a set of basic digital skills, covering information and data literacy, online communication and collaboration, digital content creation, safety and problem solving" (Brolpito, 2018). Mobile technology tools such as iPads, iPad mini, mobile applications, tablets, palm devices, e-readers and smartphones are becoming real-world tools that should be integrated into modern instructional practices to support digital learners and to promote meaningful learning (Arokiasamy, 2017). Thus, digital competences may range from technical competences, such as the use of software and hardware, to cognitive competences, such as evaluating online information, collaborating in a digital environment, and maintaining digital safety.

Therefore, acquiring and further developing digital comptence has become essential for everyday life and a fundamental competence for full participation in the digital society (Chovanova Supekova et al., 2023; Sydorchuk et al., 2024; Warschauer, 2003). As noted by Kovacs & Vamosi Zarandne (2022), digital skills are increasingly regarded as *must-have soft skills*, not only in the professional sphere. According to the European Commission (2022), basic digital skills are indispensable for daily life and employability, underpinning engagement in the digital world, they have become necessary for both daily lives and employability, setting foundations for embracing the digital world; it is projected that in the near future, 9 in 10 jobs will require such skills. Job vacancy analyses indicate that employers often expect candidates to have data visualization skills, such as proficiency in Tableau, Google Charts, Microsoft Power BI; knowledge of data visualization principles and best practices; and famiiliarity with programming languages such as R and Python (Zavyiboroda, 2022). For this reason, an important aspect of governing policy in many developed countries is guaranteeing citizens' basic rights, including support for acquiring digital skills, which will contribute to a more just and economically successful society (Brynjolfsson & McAfee, 2014; Mishchuk, 2019; Kangalakova et al., 2025).

The European Commission (EC) has repeatedly held consultations with stakeholders to develop and update digital competence frameworks for learning and employability. In 2022, the European Commission (EC) published the Digital Competence Framework for Citizen 2.2, which includes five competence areas (information and data literacy; communication and collaboration; digital content creation; safety; and problem solving) and eight proficiency levels, ranging from foundational to highly specialized (Vuorikari et al., 2022). Today, DigComp 2.2 is considered a pan-European tool for improving citizens' digital competence, supporting policy development in this field, and planning educational initiatives aimed at raising the digital competence of specific target groups.

For a long tome, the dominant approaches to measuring digital competences included: 1) self-assessment of respondents' skills, which formed the basis of two large-scale population survey projects, Web Use (Hargittai, 2005) and Digital Skills to Tangible Outcomes (Helsper et al., 2015; van Deursen et al., 2016); 2) performance tests, requiring respondents to complete specific tasks during the study. These methods often start with researchers' overestimated expectations about respondents' digital competences, which complicates the objectivity of assessing novice users. Another problem is that the assessment of digital competence is often reduced to overly generalized characteristics, based on the ITU classification (2018). However, even such approaches make it possible to identify a digital competences deficit. For example, results of an analysis of digital competences development in Ukraine showed their overall low level and only modest progress (the share of the population with *No skills* and *Low skills* decreased from 53.0% in 2019 to 47.8% in 2021) (Ministry of Digital Transformation of Ukraine (2021). A survey of Ukrainian civil servants also revealed an insufficient level of certain digital skills, with the most obvious gap being the area of «digital content creation» (Bilan et al., 2023).

A number of studies conducted by Barnard et al. (2013), William et al. (2017), Pachis (2018), Cruz-Jesus (2018), Aikins (2019), Fang et al. (2019), Otioma et al. (2019), Song et al. (2020), Huxhold et al. (2020), Peine & Neven (2021), Vercruyssen et al. (2023), and Livingstone et al. (2023) have shown that the level of digital literacy and competences depends on factors such as age, gender, education, social status, urbanization, income level (including

in rural areas), internet cost, economic freedom, access to electricity, self-efficacy, extraversion, and openness to experience.

In the context of digital transformation of the economy, especially in the post-pandemic period, digital skills have become one of the competencies determining success in professional activity – not limited to the IT market and e-commerce, with which digital competences were previously strongly associated. Among the sectors where demand for digital competence has grown significantly due to the need for digital tools are: financial and insurance companies (Csiszárik-Kocsir, 2022; Mazurchenko et al., 2022; Roy & Vasa, 2024), the tourism industry (Carlisle et al., 2023; Keller & Printz-Markó, 2023), educational institutions (Kupchyk et al., 2025; Rubach & Lazarides, 2021; Staniec et al., 2023), public administration (Bilan et al., 2023; Ortina et al., 2023; Szedmák et al., 2025), healthcare sector (Kerr & Houten, 2020; Lukács et al., 2023), industrial technologies (Hossain et al., 2025; Smieszek, 2019), etc. The demand for digital competence extends even to music education, where students are actively involved in designing and creating musical instruments through digital technologies (Falkenberg et al., 2020).

Digitalization of different sectors contributes to economic growth and macroeconomic stability (Oliinyk et al., 2021). Contemporary research on sustainable development emphasizes the role of smart technologies in transforming transport and logistics systems, particularly in developing digital competences for effective management (Vovk et al., 2025). Furthermore, the integration of transport management systems demonstrates significant positive correlations with organizational performance, highlighting the importance of digital skills in modern logistics environments (Makheti & Nyile, 2025). Successful use of e-government opportunities has helped reduce corruption and increase transparancy in public dialogue (Androniceanu et al., 2021; Androniceanu et al., 2022; Bilozubenko et al., 2025; Darmawati et al., 2024), improve public service quality (Badruddin & Yapid, 2019; Scupola & Mergel, 2022), and expand opportunities for cooperation with business and the community to achieve strategic goals (Bartuseviciene & Butkus, 2024: El Ammar & Profiroiu, 2022), including sustainable development (Zahid & Haji Din, 2019; Burlacu et al., 2021). At the same time, skepticism about digital competences also exists in academia. Some scholars have questioned whether digital competence directly translates into economic success or other positive social outcomes (Straubhaar et al., 2012).

Overall, the development of employees' digital skills has facilitated the successful use of competitive advantages and helped avoid or mitigate economic disruptions, the risk of which was high during the COVID-19 pandemic. Unsurprisingly, that period saw an incrrease in the use of remote learning and empoyment methods, particularly telework (Avram et al., 2021; Iwashita et al., 2021; Lipták et al., 2023). Company leaders recognized the importance of systematically implementing digital skills development approaches at the strategic level (Mazurchenko et al. 2022), which also became relevant for SMEs (Korcsmáros et al., 2025; Tutar et al., 2024). Incorporating professional development programs into employer value propositions became relevant and widespread (Samoliuk et al., 2022). However, companies' choices of digital training types for staff differ significantly, especially by company size – micro and small enterprises have fewer opportunities. Kergroach (2020) observes that the factors shaping this issue present a complex interplay, involving time constraints, finnancial resources, the availability of tailored training opportunities, awareness of free or subsidized online learning networks, and the adequacy of provision to address digital skills needs.

Tinmaz et al. (2022) highlight the impact of digital literacy on various aspects of human life, such as education, business, health, and governance. Other studies have shown that digital competences have a significant impact on employee productivity (Hadiansyah et al., 2024; Saeful & Ekhsan, 2024). At the same time, a study conducted in rural China between 2014-2018 demonstrated that acquiring digital competences among the rural workforce contributed to rural employment and entrepreneurship: each 1% increase in digital skills raised non-farm employment and entrepreneurship by 3.03% and 2.11%, respectively (Wang et al., 2023).

However, many recent studies emphasized the fact that there is a gap between the existing and needed digital competences to respond to the challenges of the digitalized workplace in the future (Siddiqui et al., 2022; Mazurchenko et al., 2022; Oberländer et al., 2020; Lingga, 2020). For example, a nationwide German survey in 2016 revealed that more than two-thirds of employees constantly feel the need to improve their competences at work due to technological innovations (Arnold et al., 2016). Similarly, a survey of public sector employees in South Africa revealed a significant shortage of advanced digital skills, particularly in areas such as Artificial Intelligence and Big Data, alongside a smaller gap in intermediate skills and overall lack of qualified professionals to fill various digital positions in the sector (Manana & Mawela, 2022; Yarovenko et al., 2024). These competences are coming increasingly important and often determine successful employment (Woźniak-Jęchorek, 2023), as well as business model success, such as improving supplly chains (Golubtsov et al., 2025) and developing the creative economy (Schinello, 2025).

Difficulties in acquiring and applying digital competences are also typical for graduates of educational institutions, who often note a mismatch between their current level of competences and labor market requirements (Pažur et al., 2023). Morgan et al. (2022) studied the perceptions of Australian students regarding their digital literacy. It was found that the lowest skill levels were in "using digital information, specifically in terms of evaluation and determining bias and quality of information" and "the highest levels of proficiency were for social literacy skills, such as communicating appropriately online" (Morgan et al., 2022, p. 1). Additionally, work experience and length of time in higher education had positive effect on digital literacy levels (Morgan et al., 2022). In the meantime, a survey of 4,880 registered members of a professional association of Business and Economics graduates revealed that four out of the five analyzed dimensions of digital competence (communication, content creation, safety and problem solving) influenced candidates' suitability for jobs (Periáñez-Cañadillas et al., 2019). These same trends are observed in the modern labor market, where digital skills are a typical requirement for qualified workers, often emphasized in job vacancy descriptions (Roshchyk et al., 2024).

All digital skills develop over time in both formal and informal educational environments (Leahy & Wilson, 2014). In this regard, Romi (2024) stressed the importance of paying greater attention to the adaptability of curricula and training courses to bridge the digital skills gap between those acquired in education and those required by employers.

Despite extensive research on digital competences, important gaps remain. Much of the literature (Barnard et al., 2013; Huxhold et al., 2020, Livingstone et al., 2023, Otioma et al., 2019; Song et al.2020; Peine & Neven, 2021; Vercruyssen et al., 2023) has concentrated on the determinants of digital competence acquisition at the individual level, including demographic and sociocultural factors, opportunies, and constraints. Similarly, other works have examined the impacts of digital competences at different scales – individual, business,

and macroeconomic (Mazurchenko et al., 2022; Melnyk et al., 2025; Periáñez-Cañadillas et al., 2019; Oliinyk et al., 2021; Roshchyk et al., 2024; Samoliuk et al., 2022). However, relatively little is known about which specific digital competences contribute most to career success. While sector-specific requirements for hard digital skills are undeniable, a set of transversal skills – such as the ability to search, filter and evaluate data, communicate securely and effectively, and creatively use digital content, etc. – may represent universal components of career success.

The present study addresses this gap by identifying the digital competences most strongly associated with professional advancement and higher earnings. We do so in the context of Ukraine, a country undergoing accelareted digital transformation under the extraordinairy pressures of war, where digitalization is being rapidly integrated across sectors – particularly employment – for security reasons.

Given the above, our study ***aims*** to assess the role of university graduates' digital skills in their professional careers.

Our analysis is guided by the following research questions (RQs):

***RQ1:*** Is university education an effective driver of digital competences development, or are these competences primarily acquired independently in the workplace?

***RQ2:*** Which digital competences are most developed among graduates who have achieved career success as top managers, and how dot they differ from those of graduates with more modest career achievements?

***RQ3:*** Which digital competences are characteristic of graduates with the highest income levels?

To answer these questions, we conducted a sociological survey of university graduates under the age of 35, currently employed in diverse roles in Ukraine and abroad, as well as among entrepreneurs and unemployed graduates. To our knowledge, this is the first study that measures both the development and practical use of digital competences among graduates with diverse professional experience, covering all 21 competences defined in the Digital Competence Framework for Citizen 2.2 (DigComp 2.2). The findings provide important insights for the improvement of degree programmes and for strengthening university – labor market cooperation in the joint development of students' digital competences.

## METHODS

The data for the analysis were collected through a sociological survey of university graduates in Ukraine under the age of 35 (a demographic group whose careers are most strongly shaped by the use of digital technologies) with at least one year of professional experience. Only graduates with work experience were included in the survey, thereby ensuring their ability to assess the relevance of their digital competences.

The methodological basis of the study was the DigComp2.2 (Vuorikari et al., 2022), which serves as the primary reference document for assessing digital competences within the EU. According to DigComp2.2 scale, each competence is evaluated on a 8-point scale, ranging from the lowest level of proficiency (1 point) to the highest level (8 points, confident user).

The questionnaire was developed in June – July 2024, followed by a pilot survey in August involving 32 resondents from the target group – university graduates under 35 years of age with work experience. The questionnaire was refined based on participants' feedback.

The main survey was conducted in September – October 2024 and included 397 respondents, covering all regions of Ukraine as well as graduates residing in EU countries. Data collection relied on professional university networks: academic staff maintaining contact with alumni and staff of quality assurance departments that regularly conduct alumni surveys.

For the calculation of the confidence interval, the actual sample parameters were used: Confidence Level – 95%, Population Proportion – 50%, Population Size – 9.9 million (based on statistical data on the number of young people in Ukraine as of the end of 2021, since population statistics have not been published since early 2022). Under these conditions, the margin of error is 4.92%, which allows the survey results to be considered reliable.

In addition, the internal consistency of the survey scale was assessed using the Cronbach's alpha (α coefficient), with interpretation thresholds as follows: 0,0-0,20 - Less Reliable; >0.20 – 0.40 - Rather Reliable; >0.40 – 0.60 - Quite Reliable; >0.60 – 0.80 – Reliable; >0.80 – 1.00 - Very Reliable (Ahdika, 2017). In the present study, the overall Cronbach's alpha was 0.98, indicating a high level of consistency and data reliability.

For the RQ2 analysis, respondents were grouped acciording to employment status: non-managerial employee, middle manager, top manager, self-employed, and unemployed. For the RQ3 analysis, respondents were grouped by monthly income (reflecting current labor market conditions in Ukraine at the time of the survey): from UAH 10,000 up to more than UAH 30,000, in increments of UAH 5,000. Comparisons were made relative to the highest income group (over UAH 30,000). The data were processed using IBM Statistical Package for the Social Sciences (SPSS), version 20.

## RESULTS

Examining ***RQ1*** revealed that university education plays a more decisive role in the development of graduates' digital competences than individual efforts to improve digital skills after graduation. The most substantial increase in competences occurs during the period from university entry to gdaduation, while subsequent growth following the completion of formal education is moderate (Table 1).

At the same time, the post-graduation increase in indicators highlights the necessity of continuing independent digital skills development within professional contexts and provides further evidence of their significance for career advancement.

The self-assessment results of young people's digital competences reveal substantial differences in skill levels across various stages of professional development. At the time of university entry, the average level of digital competences was rated at 3.96 points on an eight-point scale; by graduation, this figure had increased to 5.82 points. These findings indicate a gradual yet consistent improvement in digital literacy, though the pace of growth varies depending on the specific dimensions of digital competences.

The most significant increase in digital skills occurs during university studies. The average growth during this period amounts to 1.17 points, which is considerable relative to the respondents' overall average competence level. The largest improvement was observed in Evaluating data, information and digital content (+1.62 points), underscoring the acquisition of critial thinking and analytical evaluation skills that are essential in today's information society. Marked improvements were also recorded in such categories as Collaborating in digital

environemnts (+1.41 points), Data management (+1.50 points), and Engaging in citizenship through digital technologies (+1.28 points). These findings highlight the particularly important role of universites in developing competences within the areas of Information and data literacy, Communication and collaboration.

**Table 1.** Growth of digital competences during university studies and in the workplace.

| | | At university entry | At graduation | At present | Increase during university studies | Increase in the workplace |
|---|---|---|---|---|---|---|
| C1 | **INFORMATION AND DATA LITERACY** | | | | | |
| C1.1 | Browsing, searching and filtering data, information and digital content | 4,42 | 5,86 | 6,49 | 1,43 | 0,63 |
| C1.2 | Evaluating data, information and digital content | 4,05 | 5,66 | 6,33 | 1,62 | 0,67 |
| C1.3 | Managing data, information and digital content | 4,05 | 5,55 | 6,25 | 1,50 | 0,70 |
| C2 | **COMMUNICATION AND COLLABORATION** | | | | | |
| C2.1 | Interacting through digital technologies | 4,53 | 5,68 | 6,31 | 1,15 | 0,62 |
| C2.2 | Sharing through digital technologies | 4,70 | 5,77 | 6,45 | 1,07 | 0,68 |
| C2.3 | Engaging in citizenship through digital technologies | 3,90 | 5,18 | 6,08 | 1,28 | 0,90 |
| C2.4 | Collaborating through digital technologies | 3,97 | 5,38 | 6,06 | 1,41 | 0,69 |
| C2.5 | Netiquette | 4,33 | 5,54 | 6,17 | 1,21 | 0,63 |
| C2.6 | Managing digital identity | 4,09 | 5,29 | 6,07 | 1,20 | 0,78 |
| C3 | **DIGITAL CONTENT CREATION** | | | | | |
| C3.1 | Developing digital content | 3,88 | 5,00 | 5,81 | 1,12 | 0,81 |
| C3.2 | Integrating and re-elaborating digital content | 3,96 | 5,06 | 5,69 | 1,09 | 0,64 |
| C3.3 | Copyright and licences | 3,51 | 4,67 | 5,38 | 1,16 | 0,71 |
| C3.4 | Programming | 2,37 | 3,24 | 3,72 | 0,88 | 0,48 |
| C4 | **SAFETY** | | | | | |
| C4.1 | Protecting devices | 3,81 | 4,82 | 5,50 | 1,01 | 0,68 |
| C4.2 | Protecting personal data and privacy | 4,17 | 5,16 | 5,83 | 0,98 | 0,67 |
| C4.3 | Protecting health and well-being | 4,11 | 5,03 | 5,60 | 0,92 | 0,57 |
| C4.4 | Protecting the environment | 3,96 | 5,05 | 5,69 | 1,10 | 0,64 |
| C5 | **PROBLEM SOLVING** | | | | | |
| C5.1 | Solving technical problems | 3,94 | 4,94 | 5,65 | 0,99 | 0,71 |
| C5.2 | Identifying needs and technological responses | 4,04 | 5,15 | 5,82 | 1,12 | 0,67 |
| C5.3 | Creatively using digital technologies | 3,80 | 4,93 | 5,73 | 1,13 | 0,80 |
| C5.4 | Identifying digital competence gaps | 3,60 | 4,80 | 5,50 | 1,19 | 0,71 |
| | *Mean* | *3,96* | *5,13* | *5,82* | *1,17* | *0,69* |

*Note:* Grey shading indicates above-average skill growth at the corresponding stage of professiional development

Following graduation, growth in digital competences at the worklplace is less pronounced, averaging 0.69 points. This suggests that in professional settings, young people primarily apply already acquired skills, while the process of active acquisition of new digital competences slows considerably.

The most notable workplace-related improvements are observed in Engaging in citizenship through digital technologies (+0.90 points), Creating digital content (+0.81 points), and Creative use of digital technologies (+0.80 points, reflecting the most relevant areas of practical digital skills application.

Analysis of individual digital competences also reveals persistant challenges and gaps. Progarmming consistently demonstrates the lowest ratings across all three stages (at entry, graduation, and at present), ranging from 2.37 to 3.72 points, with minimal workplace-related growth. This suggests insufficient attention to algorithmic thinking and technical aspects of digital literacy, despite the fact that not all competences in this domain are limited to highly technical knowledge, such as programming code development. At the same time, this relatively low level should not necessarily be interpreted negatively. In assessing the impact of digital competences on career success, the focus of this study was on identifying *universal* skills. Programming, by contrast, constitutes a more *hard* skill, typical of IT-oriented professionals, and thus reflects only one segment of the labor market.

Overall, the analysis of self-assessment results demonstrates a generally positive dynamic in the growth of young people's digital literacy, with the most intensive development occuring during university studies. However, after graduation, the pace of improvement decreases significantly, while certain areas (such as programming) remain at a consistently low level.

Within ***RQ2***, the analysis was conducted with respect to respondent' career positions, allowing for an assessment of how digital competence levels affect professional status and employability. For this purpose, only results considered sufficiently reliable – i.e., those with Chi-Square Tests $p < 0.05$ – were included in the analysis (Table 2).

The findings show that the most successful group – top managers – exhibit particularly pronounced differences in the development of competences such as Evaluating data, information and digital content; Interacting through digital technologies; Collaborating through digital technologies; Netiquette; Copyright and licences; Creatively using digital technologies; Protecting health and well-being; Protecting the environment. This suggests that for a modern executive, it is especially important to work with large volumes of information, make strategic decisions on this basis, and effectively use digital tools to organize business processes – particularly communication – while also being sufficiently responsible to understand the impact of technology on health (both their own and that of employees) and on the environment. Another important conclusion is that a modern executive must be a highly skilled digital technology user: in eight out of the fourteen competences analyzed in Table 2 (those with results meeting the threshold of $p < 0.05$), the manager group significantly outperforms all other respondent groups.

Middle managers demonstrate considearbly lower digital competence scores compared to top managers. The largest gaps are observed in the areas of digital collaboration, digital identity management, and knowledge of copyright. This suggests that even minor deficits in digital competences can hinder career advancement.

**Table 2.** Average ratings of digital competences across professional groups of university graduates.

| Competence | | Chi-Square Tests | | Average competence ratings by professional position | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Value | Asymp. Sig. (2-sided) | Non-managerial employee | Middle manager | Top manager | Self-employed | Unemployed |
| C1.1 | Browsing, searching and filtering data, information and digital content | 51,007 | 0,005 | 6,83 | 6,10 | 7,00 | 6,26 | 7,00 |
| C1.2 | Evaluating data, information and digital content | 61,602 | 0,000 | 6,65 | 6,01 | 6,67 | 6,10 | 6,20 |
| C1.3 | Managing data, information and digital content | 57,715 | 0,001 | 6,55 | 5,92 | 6,44 | 6,14 | 6,00 |
| C2.1 | Interacting through digital technologies | 46,950 | 0,014 | 6,62 | 5,95 | 6,78 | 6,12 | 6,40 |
| C2.2 | Sharing through digital technologies | 51,852 | 0,004 | 6,76 | 6,10 | 6,59 | 6,36 | 6,80 |
| C2.4 | Collaborating through digital technologies | 52,465 | 0,003 | 6,43 | 5,63 | 6,44 | 5,95 | 5,80 |
| C2.5 | Netiquette | 41,415 | 0,049 | 6,45 | 5,83 | 6,56 | 6,09 | 6,20 |
| C2.6 | Managing digital identity | 56,894 | 0,001 | 6,39 | 5,73 | 6,30 | 5,91 | 6,40 |
| C3.3 | Copyright and licences | 41,395 | 0,049 | 5,71 | 5,02 | 5,81 | 5,14 | 5,40 |
| C3.4 | Programming | 44,058 | 0,027 | 3,96 | 3,62 | 4,19 | 3,03 | 4,60 |
| C4.3 | Protecting health and well-being | 66,983 | 0,000 | 5,96 | 5,34 | 6,11 | 4,98 | 6,00 |
| C4.4 | Protecting the environment | 45,126 | 0,021 | 6,03 | 5,29 | 6,15 | 5,53 | 5,80 |
| C5.3 | Creatively using digital technologies | 43,294 | 0,033 | 6,10 | 5,20 | 6,56 | 5,67 | 5,80 |
| C5.4 | Identifying digital competence gaps | 74,762 | 0,000 | 5,27 | 5,83 | 4,78 | 5,64 | 5,60 |

*Note:* Grey shading indicates values in the top manager group that exceed the digital competence levels of all four other respondents groups.

Unemployed respondents demonstrate relatively high levels of digital competences, particularly in digital interaction, data analysis, and programming. However, their skills in digital collaboration and information management are less developed, which may impede employment opportunities, especially in teams working within digital environments. This indicates that while digital skills are crucial for labor market competitiveness, technical knowledge alone is insufficient – communication and organizational skills are equally important.

Self-employed individuals show average levels of digital competences, especially in the creative use of digital technologies. However, their lower scores in programming and digital security may limit opportunities for business growth and the adoption of cutting-edge technologies. This highlights the importance of digital competences not only for career advancement within organizations but also for entrepreneurship and competitiveness in the market.

Young people in non-managerial positions exhibit fairly high levels of digital competences, particularly in digital interaction, information evaluation, and data exchange. In the meantime, their programming skills remain lower, which may restrict career growth in fields requiring advanced technical expertise. This suggests that for young professionals, career advancemnt requires expanding competences in programming, digital securitty, and data management.

The analysis of differences in digital competences across groups with varying income levels, conducted within ***RQ2***, is presented in Table 3.

**Table 3.** Average ratings of digital competences and deviations from the highest-income group.

| | Competence | Overall mean score | Mean (highest-income group) | Deviation |
|---|---|---|---|---|
| C1.1 | Browsing, searching and filtering data, information and digital content | 6,49 | 6,43 | -0,06 |
| C1.2 | Evaluating data, information and digital content | 6,33 | 6,39 | 0,06 |
| C1.3 | Managing data, information and digital content | 6,25 | 6,25 | 0,00 |
| C2.1 | Interacting through digital technologies | 6,31 | 6,24 | -0,07 |
| C2.2 | Sharing through digital technologies | 6,45 | 6,41 | -0,04 |
| C2.3 | Engaging in citizenship through digital technologies | 6,08 | 6,07 | -0,01 |
| C2.4 | Collaborating through digital technologies | 6,06 | 6,07 | 0,01 |
| C2.5 | Netiquette | 6,17 | 6,19 | 0,02 |
| C2.6 | Managing digital identity | 6,07 | 6,01 | -0,06 |
| C3.1 | Developing digital content | 5,81 | 5,84 | 0,03 |
| C3.2 | Integrating and re-elaborating digital content | 5,69 | 5,77 | 0,07 |
| C3.3 | Copyright and licences | 5,38 | 5,47 | 0,10 |
| C3.4 | Programming | 3,72 | 4,01 | 0,28 |
| C4.1 | Protecting devices | 5,50 | 5,68 | 0,17 |
| C4.2 | Protecting personal data and privacy | 5,83 | 5,93 | 0,10 |
| C4.3 | Protecting health and well-being | 5,60 | 5,60 | 0,00 |
| C4.4 | Protecting the environment | 5,69 | 5,86 | 0,16 |
| C5.1 | Solving technical problems | 5,65 | 5,79 | 0,14 |
| C5.2 | Identifying needs and technological responses | 5,82 | 5,92 | 0,10 |
| C5.3 | Creatively using digital technologies | 5,73 | 5,76 | 0,03 |
| C5.4 | Identifying digital competence gaps | 5,50 | 5,73 | 0,23 |

As Table 3 demonstrates, respondents with the highest incomes possess the most advanced digital competences in the areas of Copyright and licences, Protecting devices, Protecting personal data and privacy, Protecting the environment, Solving technical problems, Identifying needs and technological responses, Identifying digital competence gaps. A particularly noticeable gap is also observed in Programming. However, a more detailed analysis of the primary data confirms that this finding applies mainly to IT specialists and therefore should not be generalized to the overall sampling.

## DISCUSSION

Digital competences are a critical component of professional success. Employers place significant emphasis on their development, explicitly including them in job descriptions – indeed, in the post-pandamic new normal, digital skills have become a standard requirement (Roshchyk et al., 2024). Offering multiple advantages at both the individual and organizational levels, digital skills represent an important subject of scientific and applied research. However, the current discourse tends to focus on broad classifications of comptenece groups, often without linking them to career-related differences.

Against this background, our study provides a new perspective – identifying those digital competences that most strongly contribute to professional success in the form of career

advancement and higher incomes, as well as examining the role of universities in fostering the digital competences necessary for such success.

The findings within ***RQ1*** confirm that university education is a key factor in the development of digital competences. Kupchyk et al. (2025) claim that a university environment characterized by technological advancement, institutional support, and continuous teacher development creates "a sustainable and effective learning environment" (p. 24) designed to foster students' digital competences "through all subjects when organizing the curriculum space" (p. 3). Thus, the greatest increase in competences occurs during studies, whereas skill improvement in professional settings progresses more slowly. The role of university education outweighs that of skill enhancement gained in the workplace. This aligns with the conclusions of Morgan et al. (2022) regading the decisive role of formal education, though it contrasts with the findings of Arnold et al. (2016), who emphasized the predominance of continuous learning in the workplace. And Ukrainian universities remain a fundamental platform for the digital socialization of youth, a fact of particular importance in the context of the war-driven transition to remote and hybrid employment.

A comparison of graduates with different levels of career achievement (***RQ2***) shows that top managers exhibit significantly higher results in key universal digital competences – information evaluation, digital interaction, collaboration, netiquette, copyright, and creative use of technologies. Similar conclusions were reached by Periáñez-Cañadillas et al. (2019), who demonstrated that communication and analytical skills are essential in determining job candidates' professional suitability. Our findings further indicate that top managers overall demonstrate considerably higher average levels of digital competences. These results highlight the necessity of continuous competence development through digital technologies for those aiming at career growth. Hard skills alone are no longer sufficient to realize career ambtions, while their formation increasingly depends on mastery of digital competence.

In addressing ***RQ3***, we established that respondents with the highest incomes are characterized by stronger competences in security, technical problem-solving, data protection, and intellectual property protection. This is consistent with the findings of Wang et al. (2023), who emphasized the positive influence of digital competences on income levels and employability. In the meantime, our data diverge partially from Straubhaar et al. (2012), who questioned the direct link between digital competences and professional success. While we did not examine mathematical causalities, our comparative analysis confirmed the tendency for individuals with higher digital competences to achieve higher incomes. These results cannot be attributed solely to the impact of the war in Ukraine. First, the majority of respondents acquired their university-based digital skills prior to the war. Second, the large-scale transition to remote employment equalized opportunities for obtaining high incomes. However, it was those respondents who invested significantly in developing their digital competences who were best positioned to capitalize on these opportunities.

Overall, our results are in line with international researches (Livingstone et al., 2023; Tinmaz et al., 2022), which underline the role of universal digital competences in professional careers. Meanwhile, the weaker development of certain digital competences during university studies translates over time into shortages of competences critical for filling vacancies (Manana & Mawela, 2022). The identified gaps in formal education should serve as a signal for universities to improve curricula, with greater emphasis on the active use of digital technologies.

## CONCLUSIONS

In this study, we tested for the first time the applicability of the Digital Competence Framework DigComp2.2 to assess the impact of each of the 21 digital competences defined in the framework on professional careers – measured in terms of employment status and income levels. Although professional success may require various hard skills, we identified a set of essential digital competences that, in the context of rapid technological development, clearly influence career achievement. In particular, the competences that should be developed irrespective of occupation or other factors include: Evaluating data, information and digital content; Collaborating through digital technologies; Netiquette; Copyright and licences; Protecting the environment; Creatively using digital technologies. These competences are most strongly developed among respondents who hold managerial positions and enjoy the highest incomes. At present, universities play a critical role in shaping the majority of these digital competences. Of course, the pace of technological change may significantly alter these patterns in the near future. Nevertheless, for higher education graduates who currently form the labor supply, these dependencies are evident and should be considered in the improvement of university curricula by institutions aiming to remain competitive providers of contemporary educational services.

Naturally, our study has certain *limitations*. These include challenges in accounting for differences in career outcomes across professional groups and the influence of demographic factors. Such an investigation requires a large-scale study with a broader sample across professions and occupational sectors in order to better understand the role of digital competences in career trajectories. This was not the objective of our study. Instead, our analysis identified universal skills – competences typical across professions and career stages – whose development can substantially enhance professional growth..

## IMPLICATIONS FOR APPLICATION AND POLICY

The practical significance of the study lies in the potential use of its findings to improve university curricula, with particular emphasis on employing digital technologies to develop critical thinking, data literacy, and digital communication. Periodic monitoring of changes in graduates' digital competences – based on the approach presented here or its refinements – can drive qualitative improvements in training content. Such monitoring would be especially valuable at the national level, involving labor market stakeholders, relevant government bodies, and educational service providers, to ensure that the results inform educational policy

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# EXPLORING LAY ETHICS IN E-HEALTH: ATTITUDES AND MORAL VALUES AMONG THE ELDERLY IN POLAND

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Abstract: *This study aims to explore the ethical values and attitudes of elderly individuals in Poland toward e-health technologies, focusing on how lay ethics differ from professional ethical considerations. Methodology: The research employed individual in-depth interviews with 20 elderly participants and uses vignettes to present ethical dilemmas related to e-health tools. The vignettes were designed to contrast various moral values such as privacy vs. survival, normal behavior vs. health benefits, and autonomy vs. equal access. Results: The findings indicate that elderly participants often prioritize human contact over technology, distrust tools that replace personal interactions, and value effectiveness but not as the primary criterion for assessing e-health tools. Concerns about privacy, autonomy, and the erosion of natural social relationships were prominent. Theoretical contribution: This study contributes to the understanding of lay ethics in e-health, highlighting the importance of considering user perspectives and moral values in the development and implementation of e-health technologies. It underscores the need for a more nuanced approach to e-health that balances technological benefits with ethical concerns. Practical implications: The research suggests that e-health technologies should be designed with consideration for user privacy, autonomy, and social interaction needs to enhance acceptance and effectiveness among elderly populations.*

Keywords: *e-health, moral values, technology, elderly, Poland, lay ethics.*


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## INTRODUCTION

The rapid development of new technologies and their application in various areas of human life is generally regarded as a move toward a better quality of life. Information and communication technologies (ICT) facilitate information exchange and speed up the resolution of many everyday issues. The application of ICT in healthcare is intended to improve the prevention, diagnosis, and treatment of diseases. Studies show that e-health solutions ease access to health services and/or treatments, while telemedicine improves the health security of populations living in rural and remote areas (Banbury, Roots & Nancarrow, 2014; Rajkumar et al., 2023) and introduces novel therapeutic processes (Ahmed et al., 2023; Almasi, Shahbodaghi & Asadi, 2022; Alter et al., 2023; Drapalik, Grodberg &Ventola, 2022; Lee et al., 2023; Ngassa et al., 2022; Tarhan, Örsal & Duru, 2023; Wang et al., 2023). However, the literature on the subject also contains inconclusive results (Amiri et al., 2021; Rochester, 2022; Sekhon et al., 2021).

Whether e-health improves the quality of healthcare depends, among other things, on social approval. Such acceptance depends on the level of trust in technology, the users' digital competence, and the extent to which the needs of end users are addressed. According to the existing measuring models, the inclination to use new tools depends on the confluence of several factors: perceived usefulness, perceived ease of use, trust, privacy, social influence, and social support (AlQudah et al., 2021; Jung & Loria, 2010; Kamal et al., 2020; Shemesh & Barnoy, 2020; Zubair et al., 2021).

Elderly people are one social group whose relations with new technologies are imagined as problematic. Research on elderly attitudes toward e-health technologies in Poland reveals mixed findings. While a majority of older adults are not enthusiastic about using ICT tools for healthcare, a significant minority (41%) support selected e-health services (Bujnowska-Fedak & Pirogowicz, 2014). Factors positively influencing e-health acceptance include urban residence, higher education, normal cognitive function, and access to computers or mobile phones (Bujnowska-Fedak & Pirogowicz, 2014). Performance expectancy, effort expectancy, and social influence are strong determinants of e-health acceptance among older adults aged 60–69 (Rój, 2022). Internet use for health-related purposes is growing, with 81% of elderly internet users seeking health information online (Bujnowska-Fedak & Mastalerz-Migas, 2015). However, face-to-face contact with healthcare professionals remains the preferred source of medical information (Bujnowska-Fedak & Mastalerz-Migas, 2015). These findings suggest a gradual shift toward e-health adoption among elderly Polish people, albeit with persistent barriers and preferences for traditional healthcare interactions. However, the studies mentioned lack an ethnographic perspective. While they indicate the general trends in the elderly population, they are not designed to extend to the real life experiences of the elderly people nor do they allow for a description of the ways in which elderly people's relations with e-health technologies are embedded in social contexts. Aspects such as state of health, family relations, care arrangements, personality, cultural frameworks determining the ethical standpoint and, eventually, the emotions felt remain largely undiscussed. At the same time, these aspects are absolutely crucial as they allow us to frame the discussion of elderly people's relations with e-health technology in human terms.

While a number of studies discuss the attitudes of elderly people toward e-health (Akenine et al., 2020; Aslan et al., 2024; Lindberg & Lundgren, 2022; Nymberg et al., 2019;

Rasi-Heikkinen & Airola, 2023; Stroetmann et al., 2002; Terp et al., 2021), the ethical issues related to e-health and its use by the elderly are rarely explored. In particular, little is known about the perspectives of elderly service users. This gap in the literature is all the more noteworthy given the steady increase in the use of e-health technologies (Jokinen, Stolt & Suhonen, 2021, p. 255).

Meta-analysis of the available research aimed at the ethical assessment of e-health technologies by their (potential) users spotted four main topic areas: (1) privacy in e-health (users/citizens express concerns about sharing information, emphasizing the need to protect privacy by controlling with whom it is shared); (2) beneficence and non-maleficence in e-health (users felt the benefits outweighed the harms, but with concerns that third-party access to protected e-health data could result in: the addition of false information, which would lead to poor medical decisions; misuse, possibly leading to social isolation, stigma, discrimination or rejection at work; the provision of a lower level of care); (3) justice in e-health (attention is drawn to the difficulties associated with access to e-health due to the lack of digital literacy, low mental capacity or numerical skills, questions of affordability; (4) trust in e-health (trust in e-health depends on the effectiveness of e-health systems, and citizens desire competent support and human contact in solving health problems) (Jokinen, Stolt & Suhonen, 2021, pp. 257–264).

The above review illustrates how e-health raises a number of moral concerns among various categories of users. Hence, we designed a study focused on attitudes toward e-health technologies in one specific group, that is, elderly people. We wanted to understand the ethical values involved in assessing the new tools put to use in specific social contexts. To do so, we prepared four stories involving some ethical dilemmas. Our aim was to observe how people practice lay ethics in response to the stories designed by our research team and whether people's concerns are in any way parallel to the central concerns mentioned in academic work on applied ethics and moral philosophy. The five main moral concerns we chose to build our stories around are: well-being (or welfare), autonomy (or freedom), dignity (or esteem), a conception of positive freedom (about what "normal" or "natural" behaviors consist of), and equal (or fair) distribution. In the methodology section below, we lay these out, showing how each corresponds to a key moral theory.

## METHODS

Our team consisted of an anthropologist, a philosopher and three sociologists. We began the research with a pilot study in Lublin – a medium-sized city in Poland. We invited a small group of elderly people to participate in discussions about the opportunities and barriers influencing the use of digital technologies. We conducted a quantitative self-assessment of their digital competences and their willingness to learn about the possibilities afforded by digital technologies. Additionally, we conducted a focus group with eight elderly women during which we talked about the e-health tools currently being used in healthcare. At this stage of the research, we found that the seniors were relatively digitally competent, eager to learn more about the usage of computers and smartphones (including for the health purposes), but still concerned about the misuse of new technologies, the fact that this may distance

people from natural/normal/healthy social behavior. They found learning the new technological solutions applied in healthcare was challenging.

Based on these two preliminary collaborations, we concluded that in the face of e-health, the elderly are constructing their own lay ethics, which could differ in relevant aspects from the ethical considerations of professional ethicists. We therefore decided to find out how the elderly evaluate the implementation of specific e-health tools in hypothetical situations. To this end, we decided to use vignettes as a method (Barter & Renold, 2000). One of us had previously worked with this methodology while conducting research with children (Witeska-Młynarczyk, 2019). We constructed four short stories featuring the elderly and some aspect of e-health technology, which we then presented during the individual interviews. Each story had three elements: (1) a description of an elderly person's health problem and current living situation; (2) the use of a specific e-health tool to help the elderly person proposed by a family member or nurse; and (3) a description of how the tool works. Each story was intended to have a specific moral conflict (moral value vs. moral value) that we noticed ourselves. In this way, we also wanted to find out whether the perception of a given technology would be different among laypeople and professionals. The process of creating the vignettes began by listing the moral/ethical values that are central to the history of moral philosophy (ethics). In what follows, we first list those moral values and the traditions in moral philosophy that exhibit them and then subsequently describe the vignettes.

The decision to use vignettes arose in the early stages of designing the survey and stemmed from a desire to make the social survey more like the thought experiments used in ethics research. In addition, research involving asking elderly people for their opinions on new, often unfamiliar technologies required, in our view, an adequate explanation of how they worked. Vignettes as representations of realistic and concrete scenarios allowed the respondents to speak about difficult topics without having to refer to a personal situation while involving them emotionally in the stories presented, making the answers more likely to be authentic, varied and rich than those we would have obtained using abstract questions about specific technologies.

## Ethical Values

1. **Physical welfare (utility)**. One key goal of e-health is to improve the happiness or welfare levels of users. This focus on happiness and welfare is central to the moral theory of utilitarianism, which is a form of consequentialism focused on utility (Bentham, 1789; Singer, 1993). It holds that morally right conduct is the conduct that leads to the highest levels of utility or happiness. On this view, the goodness or badness of an act depends on the consequences. If the consequences are good, then the acts that have led to them are good. In what follows, we concentrate on just one version of utilitarianism: "hedonistic utilitarianism." According to hedonistic utilitarianism, utility is defined as what maximizes pleasure and avoids pain. To be fully clear, in this article we do not intend to make a contribution to ethical theory, but to lay ethics, by which we mean ethics as used by people (and not specifically moral theorists). For this reason, and in order to operationalize welfare, we identify two core dimensions of welfare: the importance of improving survival rates, and avoiding physical distress. That is, we shall take an act or choice to be furthering well-being and welfare when it prolongs the life of an individual or improves that individual's condition while reducing

pain or other inconveniences. We do this in order to understand the moral trade-off involved in choices that may improve welfare but decrease other moral values such as dignity, privacy or natural behavior.

2. **Autonomy**. By autonomy we mean the ability of a person to make their own choices, irrespective of what those choices may be. In other words, by autonomy, we shall mean the ability to decide for oneself. Autonomy is connected to values such as control, privacy and freedom. Privacy is related to autonomy in the sense that, when a person's private sphere is shielded from others and also not seenby them, it is easier for that person to live their life according to their own beliefs. For example, at home, privacy is needed in order for someone to experience freedom of choice in what to do (see the discussion in Cohen, 2002: 1-5).

3. **Dignity (respect, esteem)**. We focus on the idea that people should be enabled to maintain a certain manner or bearing (Rosen, 2012, p. 40): they should be allowed to enjoy equal esteem, and whatever they do should not lead to inferior or humiliating treatment.

4. **Normal or natural behavior according to a conception of positive liberty**. Some people have argued that the state should let people decide for themselves about what they can do as much as possible, as long as this is compatible with respect for everyone else's pursuit of the same interest. Isaiah Berlin famously called this the conception of freedom as "negative freedom." Charles Taylor, and many "communitarian" thinkers in his wake, instead defend what they call "positive freedom." In his famous essay "What's wrong with negative liberty," for instance, Taylor (1979) stressed that sometimes external interference can further freedom. For instance, pressure from friends to do a worthwhile thing with them might, in some cases, make a person do a certain thing that otherwise internal inhibitions (such as anxiety) might prevent them from doing.

The motivation to engage in positive freedom-enhancing acts, however, presupposes a view of what is the right way of living. Some behaviors are considered as good, or normal, and right. Others will need to be considered as undesirable and problematic. It is to be expected that digital tools and e-health technologies might be considered by many as "unnatural" or "not normal," which we explore below.

5. **Equal access**. An important tradition in moral and political theory stresses equality and equal treatment. For some such as Dworkin and Kymlicka, for instance, it is the lynchpin of any justified theory that it treats everyone with equal concern (see e.g. Kymlicka 2002: 3-5). A large number of specifications exist about what this equal concern may amount to, of course. But one value in e-health ethics, as in other domains of ethics, is that, whatever will be done, is accompanied by a concern for fairness and equal treatment.

## Vignettes and Initial Dichotomies

The last step in the conceptualization of the research was a review of existing e-health technologies and matching them with pairs of moral values, one of which, in our opinion, should encourage acceptance of the technology and the other encourage its rejection. We tried to select various technologies and to diversify as much as possible the context of the situation in which a given e-health technology was proposed to the characters in the fictional stories (vignettes).

**Table 1.** The Vignettes and Initial Dichotomies.

| Vignettes | Initial dichotomies |
|---|---|
| 1. Henry, an 80-year-old man, lives alone. He is recovering from a fractured femur and is undergoing rehabilitation. After the accident, his son suggested installing a camera in Henry's flat. This would allow him to check on Henry several times a day: in the morning, at noon, in the afternoon, shortly after dinner and in the middle of the night. This would also seriously reduce the risk of Henry being left unattended if he fell again. If a fall occurred, his son would use one button to call an ambulance. Medical help would arrive at Henry's home within half an hour. | privacy/autonomy vs. survival & health |
| 2. Hanna is 84 years old. She lives alone in a small apartment. She suffers from loneliness. Since the death of her husband, she has suffered from depression. She does not feel like leaving the house. She does not keep in touch with people. She is often depressed. Her family doctor has prescribed medication for her depression, but she does not want to take it because she "doesn't feel better after it at all." Her daughter lives in Ireland and visits her several times a year. During her last visit, she installed an app on Hanna's phone. She wants to buy her annual access. The app is a virtual friend that supports her, urges her to think positively and adopt healthy habits. The virtual friend is available at any time, even in the middle of the night when she feels anxious. | normal/natural vs. survival & health (psychological/mental welfare) |
| 3. Maria is 78 years old. She lives in a village with her husband. Unfortunately, she suffers from a chronic illness, one of the consequences of which is a frequently appearing and persistent cough. There is no decent healthcare where she lives. When the cough appears, the couple fear serious complications like pneumonia. Maria's husband found it was possible to annually rent an electronic stethoscope device that detects threats in the respiratory system. The rental would cost them 600 Polish zloty per year. The device would allow them to independently monitor and record respiratory sounds. The results could be sent to a doctor for immediate interpretation. Thanks to its sensitivity and the built-in artificial intelligence algorithms, the device is more effective, especially compared to the sounds that a doctor hears using a traditional stethoscope. | normal/natural vs. autonomy vs. equal access |
| 4. Antoni is 85 years old and a resident of a social welfare home. Due to his poor health, he does not get out of bed. He has trouble holding in urine and his mattress sometimes gets wet. The nurse suggests replacing the regular mattress with a new one with an electronic system for automatic moisture detection. If such a situation occurs, the nurse finds out about it and can react quickly without waiting for Antoni's request to change the bed linen. | autonomy vs. dignity |

**Vignette one: privacy/autonomy vs. survival & health**. Here, the digitization of healthcare is considered because of the expected health benefits, but the process is, on the other hand, a challenge to privacy. To see how elderly people deal with this dilemma, we prepared a scenario for them showing a proposal to install cameras in the apartment of a person in need of care.

**Relevance of this case.** Autonomy does not guarantee greater well-being or physical survival. It may lead to it, and one may think that in many instances people's physical future is best safeguarded by giving them control over it. But it is easy to see that an individual may often not be the best judge of what is good for their future health. Indeed, people engage in all sorts of behaviors that may endanger their physical well-being. This leads to an interesting trade-off between the first two values stressed in this overview. Clearly, in Henry's case, it is in his physical interest that his son is able to check on him via a camera. If Henry were to have fallen at home, his physical well-being and pain avoidance would be furthered by this

camera check. But it can also be seen that this is now how Henry himself may choose to organize things. In this case, installing a camera in Henry's home may alert his son to the necessity of summoning emergency medical help, although it may lead to non-physical forms of inconvenience that Henry may experience (such as a lack of autonomy and privacy). So, here, we contrast the values of physical welfare and privacy.

**Vignette two: normal/natural vs. survival & health (psychological/mental welfare)**. A pilot focus study showed that when evaluating e-health tools, older people worried that digital technologies were contributing to the erosion of the "natural" or "normal" social relationships they equated with face-to-face contact. We thought that this value could be contrasted with the value of survival and health, and vignette two was a story about a depressed person who is offered an AI-based mobile app designed to support her ability to cope.

**Relevance of this case**. It is easy to see how judgments of an ethical nature about a good life enter the domain of e-health. Indeed, it might be thought that talking to a virtual robot is meaningless, instrumental and not constitutive of normal or proper human relationships. The robot is fake; it is not a real person. But what if communicating with a virtual robot generates forms of physical or even mental pleasure? What if we have a trade-off between what is considered to be right, virtuous or proper on the one hand, and physical survival and pleasure on the other?

**Vignette three: normal/natural vs. autonomy vs. equal access**. Based on this first idea, we constructed a vignette that presented a proposal for using an e-stethoscope that can detect abnormal auscultation sounds. The idea was to see whether, when evaluating such a tool, older people prefer direct contact with a doctor or the autonomy of assessing their current state of health that such a device could give them.

**Relevance of this case**. This case explores two trade-offs: firstly, between normal/natural relationships and autonomy: would a person want more autonomy if they judge the costs of that autonomy to lie in unnatural relationships? And, secondly, if a certain e-health device furthers well-being but is, in fact, bad from the point of view of equal access because it is very expensive, would this be an objection to its pursuit?

**Vignette four: autonomy vs dignity**. The starting point for this dichotomy (perhaps surprising to some because autonomy should, in principle, increase a sense of dignity) was the example of a sensor that notifies nurses that a bed has been wet by an immobilized patient. Such technology can contribute to a patient's sense of dignity by not having to ask for a change of bedding or underwear, but on the other hand, it can reduce the patient's autonomy.

**Relevance of this case**. With this vignette, we explore the trade-offs between dignity and the values of autonomy and physical welfare. Steven Pinker, who rejects dignity as a moral value, has famously argued "dignity is well worth trading off for life, health, and safety" (Pinker, 2008). Pinker posits here an interesting trade-off between physical welfare and dignity. Here we explore a trade-off between dignity and autonomy. In Antoni's case, a wet mattress can be replaced before the patient even realizes he has urinated in his sleep. This may be thought of as reducing control and autonomy, even though it may be understood as reducing humiliation.

## Participants

The interviews were conducted in July 2023 with 20 elderly people living in Lublin. Their ages ranged from 65 to 85. Most research participants were former university employees who were recruited through the university's trade union. Most of the interviews were conducted at the trade union's headquarters. A few interviews were conducted at homes and one by phone. Among the people who took part in the research, half declared that they had completed higher education (11 people), seven people graduated from secondary school and two held basic vocational training. Prior to retirement, 14 people (declaring either a university degree or high school education) did white-collar work, while six (secondary or basic vocational training) did blue-collar work. Three-fourths of the respondents declared a satisfactory or relatively good economic situation.

Most seniors have experienced the effects of the high mobility of younger generations. Thirteen research participants have children who live in another city or abroad, yet, they declared being in frequent contact with their immediate family primarily by telephone or instant messaging (12 of them claimed to talk to their children in this way daily or almost daily).

Our interviewees use both PCs and smartphones. They use applications for communication, content consumption (written, audio and video), online banking, online shopping, monitoring their own behavior (e.g., pedometer, sleep). Some respondents have an individual patient account.[1] Most of them have heard of the term "e-health," but their prior knowledge was rather superficial – this referred to e-prescriptions, e-visits or to the ability to arrange a face-to-face appointment or receive diagnostic test results online.

## Research situation

We conducted the interviews in mixed settings. Most took place at the university at the trade union's headquarters, which was well known to the respondents, however, a few took place at participants' homes (if that was more convenient for them), and one was conducted over the phone (at the request of the participant). After completing each respondent's particulars, the researcher read out the content of the vignettes, which, printed in large letters on sheets of A4 paper, were additionally handed to the respondent so that they could recall the details of the story when needed. These sheets were treated as an extra, allowing more freedom and empowering the research participant. After each story, the research participants were asked about the ways Henry, Hanna, Maria, and Antoni felt in the narrated situation, and what was important to them. The same questions were asked in relation to the son, daughter, husband and nurse (for each story, respectively) who came up with the proposal of trying out a new device. The interviewer probed the research participants to imagine the way the characters in the story interacted around the topic, and what their motives were. Eventually, the research participants were asked about the changes the device would bring to the main character's life, and to come up with possible difficulties, if they could imagine any.

1 An individual patient account in Poland, known as an *Internetowe Konto Pacjenta* (IKP) or internet patient account, is a free online platform that allows patients to securely access and manage their health-related information. It serves as a digital health card for Polish citizens and residents, providing access to medical history, e-prescriptions, referrals, test results, vaccination records (including COVID-19), and details of doctor visits and treatments.

However, we did not ask about moral values that seemed potentially important to us in assessing a given technology in a given context.

## RESULTS

When analyzing the interviews, we found that for each story, we could group the interviewees' answers into three categories: enthusiasts, those who were ambivalent, and critics. These categories were helpful in sorting out the landscape of opinions and evaluations of e-health tools, so we decided to use them to construct this section of the article.

### Vignette One: The camera

In response to the idea of installing video monitoring in Henry's house, research participants referred to children's obligation to take responsibility for their elderly parents, the importance of human care for an elderly person, technology as an insufficient tool for elderly healthcare, privacy, autonomy, survival and health, and sense of security. These were prioritized in different ways.


**Figure 1.** The frequency of the categories used by the enthusiasts when responding to the first vignette.

Enthusiasts interpreted installing cameras in Henry's flat as a move toward improving his health and safety. Anna's words illustrate the most common explanation:

*[…] a lady in Legionowo died and for 5 years no one took any interest, that she did not leave the flat, that the mailbox (was brimming with uncollected letters – author's comment). I think Henry should agree.* (Anna, 71 years old, finances)

The enthusiasts did not recognize any significant problems related to the use of cameras at home. Some of the people in this group actually downplayed the importance of Henry's need for privacy. They could not come up with activities or situations that Henry would want to hide from his son:

*That he won't make a cup of tea or that he would do something wrong? What sort of wrongdoing can you do that would be embarrassing, making you hide from your son?* (Barbara, 65 years old, human resources)

For enthusiasts, the mere presence of cameras was perceived as increasing Henry's sense of security and reducing his feelings of loneliness. Cameras were also interpreted as a

medium that facilitated the maintenance of the father-son relationship. Furthermore, this technology was imagined as a way to avoid having non-related caregivers at home. For the enthusiasts, it was also acceptable for a camera to complement visits by a family member or, even, to replace face-to-face meetings, in case the son could not afford them.


**Figure 2.** The frequency of the categories used by the ambivalent group when responding to the first vignette.

The ambivalent group recognized the same advantages as those indicated by the enthusiasts (survival/health and sense of security codes) for installing cameras in Henry's house, however, they tended to place the situation in a larger context of care, which pushed their reflection into a more complex direction of kinship and morality. The important question raised by the research participants related to the ways in which the cameras were integrated into the actual care practices performed by the son (relations/children/responsibility). Eventually, even though the technology was generally assessed positively (technology/enthusiasm), in the context of family relations, when the son was not providing the proper direct care, the usage of the technology was interpreted negatively (technology/insufficiency). Moreover, for the ambivalent group, the problem of ensuring Henry's privacy was also equivocal.

Going back to Barbara's words, these provide an illustration of the hesitation characteristic for the ambivalent group. She began by noticing that the installation of cameras would increase the sense of security, prevent difficult situations and help maintain Henry's relationship with his son. She interpreted this solution as proof of the son's concern for his father's well-being. She even noticed that the cameras would protect Henry's privacy in the sense that they would allow him to avoid having a stranger as a carer staying in his flat. However, with time she became more critical. She expressed her worries about the care being limited only to video monitoring, evaluating it as inadequate. She thought the situation was not only about health but also about loneliness which, according to her, was a larger issue.

*[…] this man requires additional direct care. And the young man either cannot provide such care or does not want to provide it. At this point, there could still be different ways of providing additional care for this elderly person. And here, it seems to me that maybe he doesn't have time to deal with this issue, or maybe he doesn't want to. It's hard for me to decide. I don't know this son's situation well enough to easily judge him as a bad son. But what he does is insufficient. And, therefore, we can say that it is just a way of pushing away the sense of guilt.* (Barbara, 69 years old, office worker)

Eventually, Barbara shifted her attention to the actual intentions of Henry's son. Wondering about the motives behind the proposed solution, she suggested that the technology could be used to avoid a difficult problem.

Similar doubts appeared among the other research participants we labeled as ambivalent. The need of an elderly person to maintain contact with other people was a recurring theme. Here, the family context was crucial for assessing the meaning and value of installing the cameras. Cameras can either be used to mask the failure to provide help or they can successfully supplement real care. The son's suggestion of installing cameras was perceived by some as a sign of a lack of care and affection:

*[…] I raised children, taught them, educated them, and now I am left alone in my old age, with no one to lend a hand. Well, this moment is so sad.* (Stanisław, 66 years old, porter)

The people in the ambivalent group also underlined the importance of taking into account Henry's attitude toward being constantly monitored.

*[…] here you would have to know the person and his disposition and attitude to life. Because one person may not be bothered by it, and it's good to have a camera hanging somewhere. And the other person could feel very strange in his own home because he is aware that some eyes are looking at him from the outside. It would simply be embarrassing, so to speak.* (Stanisław, 66 years old, porter)

At the same time, most of the research participants who we placed in the ambivalent group would not mind, if they found themselves in a similar situation to Henry, that cameras were installed for them. They believed that such a solution could be helpful in a situation like Henry's.


**Figure 3.** The frequency of the categories used by the critics when responding to the first vignette.

More than half of the research participants responded with criticism to the idea of installing cameras in Henry's flat. It was clear for them that Henry's condition is serious, and he needs human care, not remote surveillance:

*So, the camera won't replace him. Will the camera give a hand? Will the camera pick Henry up? Will it perform resuscitation? That's it, the ambulance will arrive in half an hour. And the time, so to speak, of blood supply to the brain, 4 minutes, there is no supply.* (Wiktor, 69 years old, university administration)

*[…] right now we have to start, not by installing cameras in individual houses, but by convincing old people like myself that living alone at home is dangerous. How to convince*

*society that moving from a single house, somewhere in a block of flats, where no one will knock, to a housing estate, not so much a monitored one, but a housing estate where there is care available. That the nurse will, let's say, or a carer, will check on this man.* (Maria, 77 years old, university teacher)

In this group, the proposal to install cameras was clearly interpreted as a sign of carelessness and abandonment of the father:

*He* [the son] *doesn't have to do anything and he feels justified because he sees everything. Yet, this does not meet the needs of the person who is sick. He has no motivation to get fit because he feels abandoned by everyone.* (Elżbieta, 69 years old, technical editor at a publishing house)

Henry's story was understood as a tragic situation in which cameras were a necessity and, at best, a lesser evil. Some of the respondents immediately defined this situation as difficult and hopeless, and drew attention to Henry's loneliness and lack of proper care:

*[…] no way out. He has to agree to what his son proposes […] There's no way out, I guess. Is it his only son?* (Barbara, 78 years old, porter)

The critics also realized the difficult situation for the son, who was torn between feeling responsible for his father and dealing with his own affairs. Some of them drew attention to the economic situation and a larger cultural context (globalization, migration, work) that make it difficult to maintain proper intergenerational relationships.

*The son has his job. He has to earn his pension and to educate his children. I know because I took care of my mother when my father died. It's true that it was short, but I know how burdensome it is […] we no longer have multigenerational families, where children and grandchildren were taken care of because there was a grandmother or grandfather, there was one at home.* (Maria, 77 years old, university teacher)

Many of the research participants also commented on privacy and autonomy being endangered by the installation of the video cameras.

*Well, I would feel, I would look for a place where no one can see me.* (Ilona, 83 years old, university teacher)

To sum up, the critics of this solution believed that its advantages did not compensate for its disadvantages. Video monitoring did not dramatically increase health safety, while it might have replaced the care and rehabilitation services Henry really needed and, as a result, he would not be properly cared for. The surveillance seemed too much of an interference in the his private life, and many research participants pointed out that it might have served the purpose of masking the real lack of support from his son. On the other hand, people noticed that modern living conditions do not favor intergenerational relations of care and make it difficult for children of older parents to fulfill their obligations. Additionally, the difficulties were imagined to be intensified by the lack of access to care services (lack of money for hiring a carer, lack of state reimbursement for such services, lack of appropriate staff).

## Vignette Two: The anti-depression app

The second situation presented to the research participants was meant to probe people's responses in regards to the ethical values of normal/natural and survival/physical welfare when confronted with an anti-depression app. Most of the responses we got to this vignette were critical. Even the respondents we qualified as ambivalent seemed to linger toward a

critical tone. Furthermore, for the enthusiasts, depression was recognized as a consequence of a lack of human contact and it was repeatedly placed in a child-parent dyad.


**Figure 4.** The frequency of the categories used by the enthusiasts when responding to the second vignette.

Overall, the state of depression was commonly recognized as a consequence of loneliness. Hence, the topic of care and children's responsibility toward parents came up in many responses. Enthusiasts pointed out that it might be easier for people with emotional imbalances and special needs to deal with a virtual friend than with real people. The application could be also a good source of informational support for people with mental health issues:

*A conversation with an artificial intelligence app can be easier for people who do not like to share their emotions with others. […] The AI is like a talking Google. It not only provides support but it also holds professional knowledge which is helpful.* (Barbara, 65 years old, human resources)

*The elderly people are waking up in the middle of the night, they have fears of various sorts and this is really helpful. It would be helpful in my situation.* (Maria, 68 years old, court administration).

Enthusiasts do not fear digital illiteracy. The experience of the pandemic was given as an example of a trial for the elderly in terms of how they could manage with computer media communication (CMC). However, even here, doubts emerged and they related to children's duty to care for their parents.


**Figure 5.** The frequency of the categories used by the ambivalent group when responding to the second vignette.

Both the ambivalent group and the critics put the question of loneliness and proper human to human relationships and care in first place. For the critics, the application is not adequate and will not help because it does not eliminate the cause of the depression: loneliness. Moreover, they doubt whether a severely depressed person would be able to use it due to their illness or low level of digital literacy.

*To be honest, I do not see it. I would not find it supportive. An artificial person, an artificial voice, programmed reactions, no. […] I think there should be another solution. If this daughter cares for her mother, this sort of solution is a last resort. Yet, I guess, it will soon be the reality. We will be talking to the walls.* (Milena, 85 years old, store owner)


**Figure 6.** The frequency of the categories used by the critics when responding to the second vignette.

The research participants in these two groups tended to think that depression is so serious a medical condition that an application installed on a phone would not provide sufficient support for a lonely elderly person. The ambivalent group actually repeated the critics' arguments, but in a less decisive tone, allowing some space for the application to be tried out. They took a position that "the application is better than nothing," or suggested that could can be an easy, non-judgmental and accessible interlocutor "*... on the other hand, she can ask about everything*" (14, Romuald, 71 years old), while the critics rejected it all together.

The words of 83-year-old Ilona illustrate the ambivalent attitude quite well:

*I do not know, because a human needs a human. This technology may not turn on. It is different when a real person comes and evaluates the situation. If I can relate to myself, I do use a kind of a virtual club […]. It talks you into positive thinking and healthy habits. It helps me a lot. […] Yet, this is for less serious issues, when you look for some sort of support by yourself.* (Ilona, 83 years old, university teacher)

Jerzy comes back to the issue of child-parent relations by applying a larger framework in which migration shapes the landscape of care. He explained:

*It is a pity that it* [the application] *is not streaming live. Still, I think it may work. I think that this is one possible solution. This is not the only case like this. A lot of children left and the parents are alone. There are a lot of cases like this[…] If there is such a possibility and this friend can, as it was written here, support and talk to you, it is a very good idea. There are no other solutions. It is good enough.* (Jerzy, 75 years old, university teacher).

## Vignette Three: The stethoscope

The third vignette was meant to probe people's responses in regards to the ethical values of nature/natural vs. autonomy vs. equal access when confronted with new technology related to health.


**Figure 7.** The frequency of the categories used by the enthusiasts when responding to the third vignette.

Most of the responses we got to this vignette were enthusiastic. The solution was presented as bringing about calmness, a sense of security and control, as well as adding to the increased sense of agency. Some respondents said that the psychological comfort provided by the device could improve Maria's physical health:

*She will feel more secure. Maybe, the cough attacks will be less frequent, maybe they will disappear altogether. You never know what is the reason for those. Maybe it is anxiety…* (Elżbieta, 69 years old, technical editor at a publishing house)

Interestingly, in this group there also appeared a strong sense of trust in the ability to make an accurate diagnosis, "*This stethoscope guarantees her a fast and exact diagnosis*." (16, Waldemar, 66 years old), and a systemic argument implying that the use of such a device would unburden the doctors.

As observed by one of the research participants, the control that comes with the stethoscope could be even increased if a more complex application is developed:

*Well, if it was additionally attached to some app, which is observed and monitored by the medical staff, well, that would be brilliant!* (19, Zbigniew, 72 years old, bank clerk)

The enthusiastic research participants considered digital literacy as a potential issue to be solved for elderly technology users. Some people underlined the need to teach Maria how to use the device, however, all of them were positive about the possible outcome.


**Figure 8.** The frequency of the categories used by those in the ambivalent group when responding to the third vignette.

Among the people who felt ambivalent about the device, the issue of digital literacy grew bigger. Would people in older age manage to use the stethoscope properly? was a recurring question. Another one concerned the accuracy of the new technology when compared to actual visits to the doctor.

Wiktor, 69 years old, brought up another argument – that the device may be designed to uncover certain causes of symptoms and not the others, so there was a threat built into the technology that the users would calm themselves and neglect other medical tests. He expressed his anxiety about being overly reliant on one e-health tool.

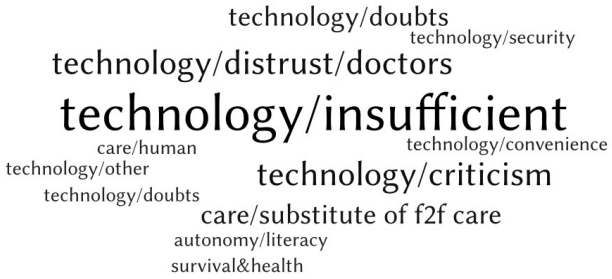


**Figure 9.** The frequency of the categories used by the critics when responding to the third vignette.

The critical opinions about the stethoscope implied that such a device may be not be trusted by doctors, who would not treat such measurements seriously. Also, the arguments from the ambivalent group about the fact that the device is not capable of providing full information but, instead, gives a very narrow picture of the ailment, was raised.

*This would not make the work short! Seemingly, it makes contact with the doctor easier. In reality, it is not easier for the doctor nor for the patients. It is one more gadget.* (Barbara, 69 years old, office worker)

*Direct contact with the doctor is best. He will examine […] There is no such machine… The doctors themselves sometimes have problems diagnosing, so, let's not mention such a device. These are the shortcuts because there are not enough doctors.* (Artur, 69 years old, construction worker)

Artur brought up the systemic argument again, yet, differently to the enthusiasts, the presence of the device was understood by him as a strategy for lowering the costs of healthcare and managing an understaffed health sector. He argued for the stethoscope to be a poor option. He did not believe in technology replacing humans.

## Vignette Four: The mattress

The fourth situation presented to the research participants was meant to probe people's responses in regards to the ethical values of dignity and nature (social relations/human care).

Most of the responses we got to this vignette were enthusiastic.


**Figure 10.** The frequency of categories used by the enthusiasts when responding to the fourth vignette.

The enthusiasts perceived the use of a smart mattress in this case as increasing the comfort and standard of living for elderly people with urinary incontinence.

*Antoni should be happy that such a device exists and that someone invented it. And someone will come earlier so that he doesn't have bedsores or other problems with urea. Very good idea.* (Jerzy, 75 years old, university teacher)

Most often, the technology was perceived as helping to avoid the negative consequences of being bedridden, like bed sores. Yet, the notion of "being cared for" was also a visible factor in relation to dignity.

*Well, he definitely feels that someone cares about him. So, he's not such "a vegetable," so to speak.* (Elżbieta, 69 years old, technical editor at a publishing house)

One of the research participants shared his thoughts that Antoni could even improve his social relationships thanks to this technology, in case he shared a room with someone else who would be bothered by the smell of urine. The research participants in this group pointed out that this solution would allow the nurses to react quickly to the needs of elderly people by changing the bedlinen – another important element for the sense of dignity. Furthermore, the research participants found the issue of communication between the medical personnel and the elderly person important. In a few responses, people stressed the need for delicacy and respect while communicating about such issues with seniors, as they are perceived as shameful.

*The whole situation, not only the proposal to change the mattress, is difficult and embarrassing for Antoni, which results from the intimate nature of the problem.* (Waldemar, 66 years old, driver and mechanic)

He noted that the first reaction may be shame, but he believed that Antoni should overcome this shame and agree to use a mattress with sensors.

In this group, the motivation of the medical personnel to introduce the new solution was explained positively. The nurse was perceived simply as a good carer, who wanted to perform her job well. Yet, one person voiced the idea that this technology could work as a form of pressure on the nurse who would not be able to ignore people's needs anymore. The research participants also underlined the fact that this new solution would allow the nurse to have more time for other patients, which they valued positively.

*We know how busy nurses are in every hospital, in every nursing home, so I think it would shorten the actual waiting time. It would even improve the comfort of the nurse, because she wouldn't have to feel or look at them, and she would react when it was necessary.* (Barbara, 65 years old, human resources)

Some of the enthusiasts expressed concern about elderly people's distrust toward and fear of technology.

*The nurse has good intentions – urinary incontinence is a sad thing, she doesn't want her patients to lie in wet beds for too long, she can react quickly. Mr Antoni may prefer to lie in wet bedding because he is afraid of new things, or maybe he thinks that there is something else behind this proposal? Does this device perform any other functions? Yet, he should agree.* (Zuzanna, 75 years old, accounting department)


**Figure 11.** The frequency of the categories used by those in the ambivalent group when responding to the fourth vignette.

Among the research participants whose responses were labeled as ambivalent, the narrative of 69-year old Barbara focused on the possible resistance on the side of medical personnel toward the solution. The nurses were talked about as reluctant to react quickly and overloaded and the idea behind the mattress was framed as an additional burden and a form of control over their work. This research participant also pointed out that people with different characters may respond differently to the new technology. Another person suggested that a catheter would be a better solution, as it would provoke less embarrassment. She advised frugality when it comes to new technological solutions and an individual approach when making decisions.


**Figure 12.** The frequency of the categories used by the critics when responding to the fourth vignette.

One person was critical of the proposed solution. Again, the notion of human-to-human contact in a care situation was brought up.

*For me, these questions are abstract. It would help him if the nurse came and replaced it normally. It would be a relief because she wouldn't have to keep checking. I suspect that this gentleman would not be so pleased, because the lady would not appear so often. Besides, he has nothing to say. He wouldn't even know they installed something like that* [laughter]. (Artur, 69 years old, construction worker)

This research participant also expressed a distrust toward technology and stressed the possible side effects it may have due to radiation. His standpoint could be summed up in the following way: as a risky solution, technology should not replace human care.

The analysis showed that assessment of e-health tools is sensitive to the social context within which it is embedded. It matters who proposes the solution, how and in what circumstances. The most distinct was the participants' reaction to the first two stories (having parent-child relations at the center) versus the last two (where the highlighted relationship was between an elderly person and medical personnel). The stories in which children were the protagonists evoked many emotions and the theme which stubbornly re-occurred was that of new technologies equaling the abandonment or neglect of children's duties toward their parents. This finding may be particularly telling about the Polish context in which family is predominantly understood through blood ties which are highly valued and tied to moral obligations operating in the multiple contexts of care (Maciejewska-Mroczek & Witeska-Młynarczyk, 2021). Here, the issue of privacy, autonomy or survival/health became secondary to the "normal" or "natural" order of things, that is, kinship relationships based on emotional warmth and the moral obligation to care for elderly parents. The research participants were more prone to seeing technology as a positively valued support when it was configured within the relationships with medical staff. In the second case, the innovations sparked less controversy.

## DISCUSSION

In this study, we invited elderly Polish people to discuss the moral dimension of e-health. We did so by animating one-to-one discussions around fictional stories presenting the engagement of elderly people with new technologies related to health. Our starting point was

a contemporary academic work on applied ethics and moral philosophy. We used key concepts in moral theory to design the vignettes. Our aim was to understand the extent to which lay ethics corresponded with the propositions advanced by moral philosophers. These provided the guiding framework for our discussions. Another, more anthropological, aim was to sketch the emic perspective on the bigger societal transformations (in particular, technological advancements in the area of healthcare) within which elderly people are ascribed a potentially vulnerable position. The stories we prepared for the research participants were taken as an incentive to morally comment on the changes irritating the fabric of contemporary society. The people we spoke to referred to the sense of loneliness, the quality of human relations (in particular, parent-child relations), migration patterns, the quality of healthcare, the way technology is meant as a replacement for something expensive. Remaining in a dialogue with these large frameworks, the research participants expressed their moral standpoints in relation to concrete examples of the encroachment of e-health technologies into the lives of their fictional peers. Here our collaborators did not speak in unison. The participants used various standpoints listed by philosophers and they engaged in sensible moral discussions and provided a number of arguments for the primacy of autonomy, privacy, dignity, survival or the natural order in each context. We grouped the answers into three categories depending on the attitude people took to e-health technology entering a specific social situation (i.e., the enthusiasts, the ambivalent group, the critics). Since the proposed categorization does not exhaust all the possible ways of ordering the research material, we suggest that the most valuable part of the research material consists of the illustrations of acts of lay moral reasoning our collaborators undertook in response to the stories we scripted.

The use of the vignette method can give rise to some limitations of the study. They are great experimental tools: by modifying the parameters of the same vignette, it is possible to compare the reactions of the respondents. In our study, we did not do this, and the stories included in the vignettes are the result of some arbitrary decisions. How we described the main character's health situation, who the person proposing to use the new technology was, can determine how it will be evaluated. Only when analyzing the content of the interviews did it occur to us that the proposal to install cameras could have been judged somewhat differently if we had placed a daughter in the vignette instead of a son (in Polish culture, daughters are still more responsible for the care of their parents than sons). However, it is worth noting the potential of this method: due to the possibility of controlling such parameters, the vignettes can be used to study attitudes toward technologies unfamiliar to the respondents and to observe the process of making moral judgments about a given technology, imagined uses or unexpected consequences.

The results obtained should be related to the population of people living in a large city. These are people who have relatively high digital competence and show a positive attitude to technological novelties, therefore, the results of the survey could be different among older residents of small towns and villages. On the one hand, a lower level of education and being in a more conservative environment could result in less trust in new technologies. On the other hand, the loneliness and isolation of the elderly living in low-density areas could make e-health tools appreciated for their ability to break the barrier of the long distance from informal and formal caregivers or medical professionals.

## IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

We believe that our material spots a number of areas worthy of further exploration. For instance, we noticed that what we call "the elderly generation" is, in fact, a very diverse group of people who can experience different health issues at different times in later life. For example, the vignette in which Antoni was a protagonist seemed quite abstract to many of our collaborators who perceived themselves as occupying a different stage of life. His situation laid dramatically different conditions for experiencing autonomy, security, human contact or dignity in comparison to the elderly figures featured in the other three stories. We hypothesize that the hierarchy of the importance of the values mentioned by seniors eventually depends on the stage of life they occupy during old age.

Our choice of methodology proved that not only the experiences of elderly people are embedded in social contexts but also that the scope of possible moral movement is not simply defined by age, but also by other factors such as health, family situation, personality, dominant cultural frameworks, placement. In Poland, institutional care for seniors is still associated with "less humane" care, an experience of abandonment, a risk. To think about placing your elderly parent in an institution involves ethical dilemmas. Caring for elderly parents is a tough road through a network of imperfect private and public institutions, with a lack of flexible at-home care solutions or a legal framework enabling engagement in practices of care without quitting one's job. Such structural conditions produce much intergenerational anxiety, difficult to mend with the help of new technologies. Eventually, care for the elderly is also unevenly distributed. The demands rest mostly with females. Last, but not least, it cuts through the imagery of being a modern, nuclear family or a postmodern single person or in a flexible relationship and, here, the traditional values of the multigenerational family do not fit very well. We suggest that the fear and ambivalence evoked by e-health do not come from the technology itself but shall be viewed as rooted in the ways in which different generations collectively transform their values and how technology is interpreted within these various, emotionally loaded social layers of meanings.

Examining the ways in which potential user groups of new digital health technologies assess the ethical implications of their use is useful for designing such tools and the policies that support fair and safe implementation. They help understand what factors influence the trust of users and their expectations of e-health technologies. For example, the finding from our research that older people are concerned about the social isolation that can result from the implementation of e-health tools shows that if such concerns go unnoticed, they can result in unexplained barriers to accessing new technologies, creating further dimensions of health inequality. This type of research can help to show that inequalities are not only due to different economic status, digital competence, but also to the social context, family situation, or culturally based beliefs about family roles.

This work would benefit from being developed with a greater focus on affective materiality and new understanding of the ways in which humans relate with technology (e.g., Höppner & Urban, 2019; Pink, 2015). We believe that the conversations we opened with this research are worth further exploration, maybe, also, by inviting younger generations or people inhabiting other ethnographic contexts to comment on our, or other, stories.

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# IS THERE CONSISTENCY IN ETHICAL SENSITIVITY IN ARTIFICIAL INTELLIGENCE? A REVIEW OF LANGUAGE MODELS

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Abstract: *This study examines the structural and content consistency of large language models (LLMs) in ethical decision making with a qualitative approach. Responses to basic ethical themes such as "justice", "non-maleficence", "autonomy", "impartiality", and "goodness" were evaluated using the thematic analysis method of Braun and Clarke (2006). The three-stage coding process analyzed empathy patterns, contextual transitions, and relationships between themes. The findings, supported by Python-supported frequency and variation analyses, revealed that the models exhibited high empathy and solution determination in the themes of "inclusiveness" and "communication" but low structural consistency in the themes of "religion" and "disability". The responses to the same ethical theme in different contexts were determined to carry semantic shifts. This original study emphasizes that ethical sensitivity should be evaluated based on patterns.*

Keywords: *ethical consistency, large language models (LLM), thematic analysis, empathy pattern, contextual variation.*


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## INTRODUCTION

With the rapid development of artificial intelligence systems, evaluating these technologies with technical success and ethical criteria is necessary. Large language models (LLMs), in particular, are increasingly used in sensitive areas of society such as health, law, education and content moderation, and this situation reveals the need for decision mechanisms to be compatible not only with data but also with ethical principles and norms (Jobin et al., 2019). A study has shown that 78% of users expect consistency in ethical decisions made by artificial intelligence-based systems (Mökander et al., 2022). However, it has been shown that current LLM systems give contradictory answers to the same ethical question in different contexts. This suggests that the models are inconsistent and predictable regarding ethical sensitivity. The social impact of these technological developments is not limited to the individual level, but also has institutional and systemic consequences. For example, algorithmic decisions in immigration policies or justice systems can cause inconsistency in ethical decisions, leading to irreversible harm to individuals. In addition, value distortions in the outputs of models create trust problems in a wide range of areas, from environmental sustainability to social equality (Gabriel, 2020; Cath, 2018; Hagendorff, 2022; Binns, 2018; Mittelstadt et al., 2019; Seniutis et al., 2025). The increasing integration of AI systems extends to operational domains such as logistics and warehouse management, where artificial intelligence technologies demonstrate significant potential for optimizing processes while raising questions about ethical implementation and decision-making consistency (Angammana & Jayawardena, 2022). Similarly, the development of sustainable and smart logistics systems requires careful consideration of ethical frameworks in autonomous decision-making processes (Vovk et al., 2025). Most of the literature discusses the codability of ethical principles in artificial intelligence systems, but does not sufficiently address how these principles evolve and vary in context (Andrus et al., 2021; Weidinger et al., 2022). For this reason, this study was designed to question thematic coherence in ethical sensitivity and critically examine the responses of language models in this direction.

Studies on assessing ethical consistency in AI systems have gained significant momentum in the post-2018 period. One of the first systematic approaches in this field is the study by Raji et al. (2020) that shows the direct impact of algorithmic auditing processes on ethical outcomes. However, most of these studies have not examined the ethical sensitivity in the outputs of AI systems in terms of normative consistency (Crawford & Paglen, 2021). These applications underscore the necessity for comprehensive ethical frameworks that address both technical performance and normative alignment. In some studies, it has been observed that the responses of LLMs to ethical dilemmas often vary depending on the context and produce inconsistent outputs according to predefined ethical principles (Zhou et al., 2023). This suggests that the models are not trained in a specific moral framework, and their ethical decisions are based mainly on data-based correlations. Nevertheless, some studies have shown that language models can provide morally acceptable answers in specific contexts (Tamkin et al., 2021; Arora et al., 2023). Most of these studies have been conducted under controlled experimental conditions with limited data, which raises the issue of generalizability. On the other hand, there has been no sufficient comparative analysis of how ethical principles are interpreted in different cultures; this deficiency makes the cultural context blindness in the ethical responses of LLMs visible (Santurkar et al., 2023; Birhane &

Prabhu, 2021). In addition, in the existing literature, studies that systematically classify the ethical responses given by LLMs are pretty limited (Sheng et al., 2021; Bommasani et al., 2021). Therefore, this study emphasizes the necessity of considering ethical responses thematically based on content and structural consistency.

Although studies on the consistency of large language models in ethical response production are increasing in the literature, these studies are mostly limited to measuring superficial compliance in the systems' outputs. Many studies discuss whether it is possible to train language models within specific normative frameworks, but it does not systematically examine the consistency of the responses of these systems to different ethical themes at the thematic level (Uesato et al., 2022; Kirk et al., 2023). In addition, evaluating the ethical sensitivities of models only under broad categories such as "do not harm" and "do not help" makes the analysis of contextual differences difficult and does not allow for in-depth evaluation. This situation encourages superficial analysis of the models' responses, especially in the face of multi-layered moral dilemma questions, while ignoring the normative variability in the thematic structure (Perez et al., 2022; Shevlane et al., 2023). Analyzing ethical consistency at the thematic level can contribute to artificial intelligence systems' transparency, social acceptance, and regulation. Ethical ruptures that may occur in the interaction of user groups with different cultural norms with models can only be predicted with such thematic depth analyses (Leins et al., 2023; Zheng et al., 2023). At this point, there is still a lack of systematic studies in the literature that evaluate the ethical consistency of language models in a comprehensive, comparative, and pattern-based manner (Askell et al., 2021; Schramowski et al., 2022; Ganguli et al., 2023). In order to fill this gap, this study aims to thematically code the answers given by large language models to ethical questions, make comparisons between different ethical domains, and classify possible contradictions. In addition, this analysis aims to provide inferences about the ethical consistency capacity of models by measuring contextual shifts in ethical response production.

The main problem of this study is to question the inconsistencies exhibited by large language models in ethical decision-making on a thematic level. Although LLMs can provide morally reasonable answers in specific contexts, it is largely unknown whether these answers are consistent across similar themes (Glaese et al., 2022). The study's basic assumption is that although the answers given by language models to ethical questions may seem reasonable, they do not show significant consistency in thematic integrity. There are significant variations in the ethical answers of LLMs depending on the context, and these variations transform into structurally recurring patterns in specific ethical themes (Lin et al., 2022; Zhang et al., 2023). This study aims to comparatively analyze the ethical sensitivity capacity of LLMs within the framework of themes such as “justice”, “non-maleficence”, “autonomy”, “impartiality”, and “goodness”. The research aims to contribute significantly to this context's theoretical and applied levels. At the theoretical level, it will allow for a reinterpretation of the concept of ethical consistency in a principle-based and pattern-based manner. As a contribution to the literature, this study reveals the qualitative structure of ethical response production using thematic discourse analysis and introduces a methodological approach rarely used in this field (Ji et al., 2023; Maki et al., 2023). Identifying ethical inconsistencies in model outputs can provide critical feedback for regulatory processes and LLM education (Gehrmann et al., 2023; Chiang et al., 2023; Scholte et al., 2023). The implications of the results will be multi-

layered, encompassing not only AI engineering but also human-centered design, ethical audit systems, and cultural adaptation strategies.

The research is structured within a qualitative research design framework and is based on the thematic analysis method to analyze the ethical consistency of large language models. Thematic coding will be based on Braun and Clarke's (2006) six-stage thematic analysis model. Following this structure, model outputs will be collected by creating a data set and then subjected to content analysis. The review process will progress in four basic stages: In the first part, structured questions representing ethical themes will be created and directed to the model. In the second part, the responses will be coded using qualitative analysis software, and patterns will be extracted for each theme. In the third part, these patterns will be evaluated in terms of consistency; different responses given on the same theme will be compared. In the last stage, the ethical sensitivity level of the model will be subjected to a general assessment based on the analysis results (Nowell et al., 2017; Vaismoradi et al., 2016). The main question of the research is as follows: Can large language models provide consistent and normatively acceptable answers to questions given under different ethical themes? This question will be questioned regarding technical accuracy and the context of the principled integrity of ethical decisions (Guest et al., 2012; Terry et al., 2017). In this respect, the study aims to make an original contribution to discovering contextual ethical patterns in LLM outcomes.

## LITERATURE REVIEW

The three concepts that form the basis of this study -ethical consistency, thematic response pattern, and large language models (LLM) -have been at the center of interdisciplinary research in recent years. Ethical consistency responds to normative situations with similar principles (Floridi & Cowls, 2019). This concept is addressed in a socio-technical framework, especially to increase the reliability of decision-making in artificial intelligence systems (Binns et al., 2018; Mökander et al., 2021; Lyeonov et al., 2024). While ethical consistency has been studied in human-based cognitive decisions in the past, it has recently gained measurable structures by being integrated into algorithmic decision systems. Thematic response pattern is an analytical structure used to determine how a model responds to specific moral themes. This concept is evaluated at the semantic level of the content and in terms of linguistic structure and discourse form. Thematic response pattern, the stability of thematic patterns, is a criterion that shows the level of compliance of the model with ethical principles (Gabriel, 2020; Schramowski et al., 2022; Seniutis et al., 2024). Conceptual framework for ethical artificial intelligence development in social services sector. In this context, pattern-based analyses are carried out with hybrid approaches combining behavioral modeling and discourse analysis. The third basic concept, large language models (LLMs), are machine learning systems that contain billions of parameters and can produce human-like language. LLMs first emerged as an advanced form of statistical language modeling, but today they have evolved into autonomous systems that produce outputs based on ethical, political, and social norms (Andrus et al., 2021; Bommasani et al., 2021; Weidinger et al., 2022). Therefore, when these three concepts are considered together, it is understood that ethical

performance should be measured not only by accuracy, but also by meaningful and consistent production.

Integrating AI systems into ethically responsible decision-making mechanisms is the product of deep-rooted technological, philosophical, and normative discussions. The evolution of the field has been shaped especially around themes such as "algorithmic justice" and "moral decision systems" (Mittelstadt et al., 2019). The first systematic approaches to the modelability of ethical systems in machines were developed by Binns (2018), and this work was accepted as a fundamental reference in establishing a bridge between political philosophy and machine learning. At the same time, the global study by Jobin, Ienca, and Vayena (2019), in which they comparatively analyzed 84 different ethical guidelines, was an important turning point that emphasized the diversity and contextuality of ethical principles in AI. The experimental study by Glaese et al. (2022) investigating the ethical alignment of LLMs through human feedback is groundbreaking in that it directly tested the level of compliance of model outputs with ethical norms. Similarly, the "normative framing" approach developed by Gabriel (2020) positioned AI ethics as a value-oriented system design, not just a set of technical rules. This approach directed the discussion of ethical consistency to the contextual evaluation of language model outputs. Weidinger et al. (2022) argued that issues such as social harm, security, and manipulation should be systematically examined regarding LLMs by mapping the ethical risk of large language models. In this vein, Schramowski et al. (2022) showed that models can "learn" human-like moral norms from data, but this learning is not limited to consistency. As a result, this research arises from the theoretical and empirical heritage summarized above. It aims to propose a new conceptual framework in the literature by structuring ethical sensitivity on a thematic level. In this context, the first sub-question of the research is as follows: "Can large language models exhibit meaningful ethical consistency at the structural level in different themes with ethical content and in-depth analysis?"

The basic concepts discussed in this study - ethical consistency, thematic pattern, context sensitivity, and large language models (LLMs) - were evaluated within a multilayered network of intertwined relationships. While ethical consistency is defined as the capacity to produce similar responses to the same normative theme despite contextual diversity, thematic pattern provides a framework that allows this capacity to be measured concretely (Hooker & Kim, 2019). The context sensitivity of LLMs has been frequently discussed in the literature as a dynamic variable that both fosters and limits the potential for ethical consistency (Birhane et al., 2022; Srivastava et al., 2022). Studies show that the relationship between these concepts can be grouped around three thematic trends. The first trend is the claim of normative fixity, which argues that ethical decisions should be based on predefined principles (Floridi et al., 2018). The second trend is the defense of context-based flexibility, which suggests that ethical responses may vary depending on the socio-cultural environment. The third trend is the hybrid approach based on inferential learning, where language models are argued to derive ethical norms from training data and model the inter-theme transitivity (Mokander & Floridi, 2021; Bai et al., 2022; Ganguli et al., 2023). The study will analyze the linguistic, contextual, and normative transitions of the responses between the themes to investigate whether ethical consistency is a structural rather than a content-based phenomenon (Ji et al., 2023; Chiang et al., 2023). The second sub-question of the study is:

"Do the responses of large language models to different ethical themes exhibit structural consistency in terms of context sensitivity and normative transitivity?"

Studies in artificial intelligence ethics have increased quantitatively in the last five years; publications focusing on the social and ethical impacts of large language models (LLMs) have become especially evident. The general trend in the literature is to measure the performance of systems in thematic areas such as harmlessness, prejudice, discrimination, and transparency (Weidinger et al., 2022; Raji et al., 2020; Bender et al., 2021). Institutional guidelines, technical guides, and normative frameworks are usually used as references in defining ethical principles (Jobin et al., 2019; Floridi & Cowls, 2019). Methodologically, artificial test sets created under laboratory conditions and survey-based user experiences are at the forefront. However, these trends cannot sufficiently examine ethical sensitivity's contextual, thematic, and patterned dimensions. Reducing ethical responses to only static principles of correctness or harmlessness makes the variability of language models in real-world interactions invisible (Brown et al., 2020; Tamkin et al., 2021; Birhane et al., 2022; Shevlane et al., 2023). On the other hand, qualitative methods such as pattern-based thematic analysis have been largely neglected in the literature. In particular, the effect of linguistic structures that show transition between different ethical themes on the normative consistency capacity within the model has not been sufficiently tested empirically (Andrus et al., 2021; Zhang et al., 2023). In line with this deficiency, this study aims to analyze patterned consistency by thematically coding the ethical responses of large language models. With this method, not only "what is said" but also "how and to what extent it is said consistently" will be revealed. In this context, the third sub-question of the research is as follows: When the ethical responses of large language models are evaluated at the thematic level, can they reveal structural pattern differences beyond superficial semantic similarities?

Most ethical assessments in AI are limited to either technical bias measures or normative perception tests based on individual user opinions. This methodological approach can indicate whether model responses align with ethical principles on the surface, but it falls short in assessing the contextual consistency of ethical responses (Binns et al., 2018; Raji et al., 2020). Furthermore, the "prompt-based" assessments used in many studies lack a systematic structure that would reduce the randomness of model responses. This creates serious criterion gaps in determining whether LLMs behave consistently across themes. One of the strengths is that studies such as Schramowski et al. (2022) and Glaese et al. (2022) demonstrate the learnability of moral norms in LLMs. However, most of these studies focus on generating "good" or "harmless" responses, neglecting the question of how consistent and principle-based responses are within an ethical framework (Perez et al., 2022; Weidinger et al., 2022; Gabriel, 2020). Furthermore, the diversity of ethical responses across different cultural or linguistic contexts has not been adequately tested (Chiang et al., 2023; Srivastava et al., 2022). Conflicting findings in the literature create uncertainty about the extent to which themes, especially those classified according to ethical principles, diverge in model outputs. For example, while some studies argue that models are strong in the principle of impartiality, others have shown that the same models exhibit apparent contradictions in justice-themed questions (Hooker & Kim, 2019; Bender et al., 2021). This suggests that ethical decisions should be evaluated not only in terms of outcome but also in terms of process. From this perspective, addressing ethical sensitivity at a structural level requires more in-depth analysis (Birhane et al., 2022; Andrus et al., 2021). In this context, the fourth sub-question of the

research is: “Do LLMs' responses to ethical themes contain structural contradictions in transitions between principles, and can these contradictions be associated with thematic inconsistency?”

This research is built on three principal theoretical axes: Normative Ethical Theories, Multisystem Decision Making Theory, and Discourse-Based Meaning Construction Approach. These theories provide an explanatory ground for analyzing the level of ethical consistency of large language models and evaluating response patterns at the thematic level. Normative ethical theories—especially deontological and utilitarian approaches—are used to understand the internal value structures in producing ethical responses by language models (Floridi & Cowls, 2019; Gabriel, 2020). While deontological ethics reads ethical consistency through the principle of adherence to fixed rules, utilitarianism legitimizes context-based ethical diversity. This duality guides the thematic pattern analysis of the study. The application of utilitarian principles to technological decision-making reflects broader discussions about the intersection of ethical frameworks with practical outcomes. Recent research examines how utilitarian approaches can be conceptually integrated with sustainability considerations in business contexts, highlighting the importance of balancing immediate benefits with long-term ethical implications (Mumcu, 2024). Secondly, Multisystem Decision Making Theory analyzes the internal consistency of decisions and their relationship to the external context based on human-like cognitive modeling (Binns, 2018; Kahneman, 2011; Srivastava et al., 2022). This theory has examined whether LLMs act in contextual harmony or patterned disunity. The third theoretical pillar, Discourse-Based Meaning Construction, aims to analyze what kind of normative structures the model constructs through linguistic outputs (Weidinger et al., 2022; Andrus et al., 2021). This approach reveals that ethical responses can be evaluated not only by content but also by discourse form. In line with these theoretical foundations, the following relationships between the variables stand out: a theoretical causal link is suggested between “ethical theme” (independent variable) and “response consistency” (dependent variable). In addition, “context sensitivity” and “discourse pattern” are positioned as mediating variables affecting this relationship (Chiang et al., 2023; Zhang et al., 2023).

## METHODS

*Research Design:* This research was designed as a qualitative thematic analysis to analyze the structural consistency of large language models in producing ethical sensitivity. Braun and Clarke's (2006; 2019) six-stage thematic analysis approach was adopted in the research. This method allowed analyzing the language model outputs at the content, pattern, and discursive levels. The research process consists of three main stages: (i) data generation, (ii) coding and thematic structuring, and (iii) pattern analysis. The study aims to examine the responses of the language model with scenarios structured within the framework of ethical principles (justice, non-maleficence, autonomy, beneficence, and impartiality) and to reveal whether these responses are consistent across contexts at the thematic level. The complexity of ethical decision-making in AI systems mirrors challenges faced in multi-criteria assessment methodologies, where digital technologies are employed to navigate complex decision-

making processes while maintaining consistency across multiple evaluation criteria (Mubarak et al., 2024).

*Sample and Scenario Set:* The research was taken from the Kaggle database, and each line includes the ethical or managerial inclusiveness principle (Accessibility) and then a sample response or implementation proposal given to this principle. There is also explanatory or guiding information on applying the relevant principle. The dataset also contains the necessary textual data that allows thematic coding for developing institutional inclusiveness policies, sampling ethical principles in education and training, testing the principled responses of artificial intelligence models in the context of inclusiveness, and ethical compliance, social responsibility, and governance analyses. The dataset has a structure that is particularly suitable for qualitative analyses (thematic analysis, content analysis) with the principle-guiding patterns it contains. Coding Process and Thematic Structuring: A three-level approach was adopted in the coding phase: open coding, axial coding, and thematic clustering (Saldaña, 2021). In the first phase, model responses were included in the content analysis process; then themes were created by combining them according to conceptual affinities. While five ethical principles were included among the main themes, empathy indicators (awareness, support, approval), solution strategies (technical, procedural, physical), and decision patterns (short-term/long-term, proactive/reactive) were coded in the cross-axes.

*Data Analysis:* The analysis process was carried out using descriptive and pattern analysis techniques, and the Python programming language was used to analyze the data. First, the distributions of ethical themes were calculated with frequency analyses; the extent to which each theme was repeated in the model outputs was revealed. Second, the extent to which subcategories such as solution strategies and empathy indicators overlapped with ethical themes was visualized with thematic transition matrices. In addition, the response examples were grouped according to contexts, contextual variation levels were calculated, and consistency between themes was compared with variation rates. The resulting patterns showed which themes the model behaved more stably or more variably in ethical decision making.

*Reliability and Validity:* To ensure reliability in the study, three independent researchers carried out the entire coding process, and blind coding principles were adhered to. The consistency between coders was measured as 0.82% with Cohen's Kappa and was considered reliable (Landis & Koch, 1977). During the creation of the themes, conceptual validity was designed to overlap with the existing ethics literature; For example, the theme of "not harm" was coded based on the biomedical ethical principles of Beauchamp and Childress (2013). Thanks to these practices, internal consistency and theoretical commitment were achieved in interpreting qualitative data.

## FINDINGS

This section examined the patterns in the big language model's approach to ethical themes with multi-layered analyses. Thematic Frequency Analysis quantitatively revealed the extent to which ethical themes were included in the model responses. At the same time, Pattern Consistency Analysis evaluated the level of structural similarity of the solution suggestions given under the same theme. Empathy and Linguistic Sensitivity Analysis provided an in-depth presentation of

how much responses were enriched with emotional expressions and the distribution of empathy types. Thematic Transition Analysis revealed frequent matches between themes by showing the extent to which the model combined multiple ethical sensitivities in the same response. Inter-Scenario Contradiction and Contextual Change Analysis examined the consistency and semantic shifts of the same ethical theme in different contexts; contextual fluctuations were detected, especially in the disability theme. Finally, Contextual Variation Analysis analyzed the differences in the model's responses to cultural contexts such as social, religious, or professional, providing important clues about cultural blindness or contextual adaptation capacity. When all these analyses are evaluated together, it is revealed that there are differences in how the model exhibits ethical sensitivity depending on the theme, context, and narrative structure.

## Thematic Frequency Analysis

In the study, thematic frequency analysis was conducted to evaluate the sensitivity level of major language models to ethical themes. The analysis process was done using Python instead of qualitative data analysis software, and the numerical equivalent of the references to each ethical theme was obtained. The ethical themes examined were classified under accessibility, compliance, inclusiveness, disability, religion, and communication. The visual representation of the analysis and the proportional distribution between the themes is given in Figure 1.

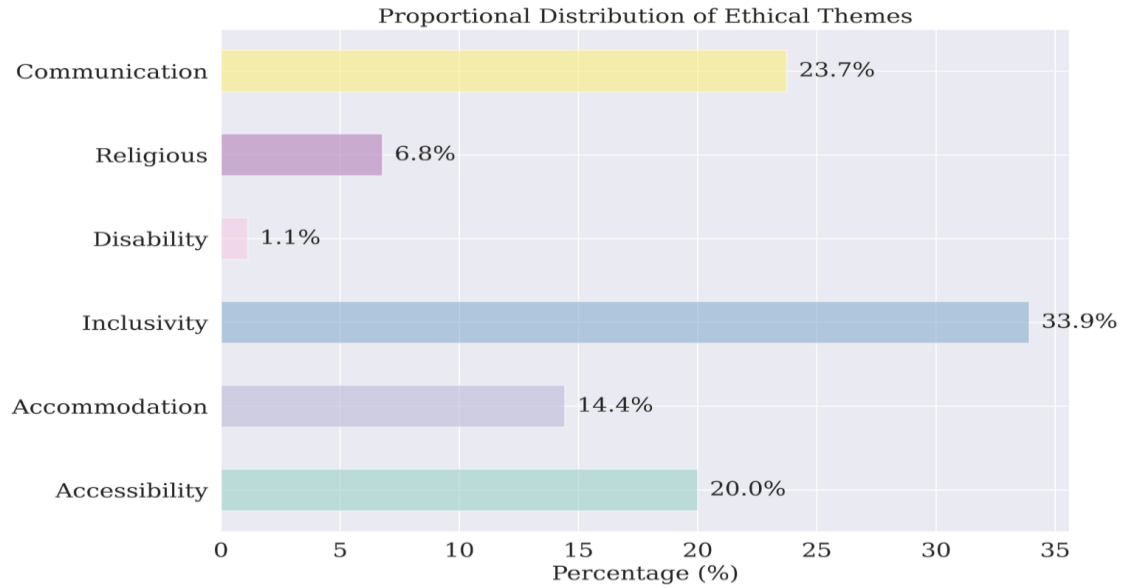


**Figure 1.** Proportional Distribution of Ethical Themes.

According to the thematic distribution matrix created in the Python environment, the most frequently referenced ethical theme was inclusiveness (n=216), followed by communication (n=176) and harmony (n=107). These results show that language models are more sensitive to social integrity, pluralism, and interactional ethical values. On the other hand, disability (n=11) and religion (n=33) themes were the least frequently mentioned topics in the analysis, indicating that the models addressed some marginal or unique ethical sensitivities in a limited way. When the cross-relationships between the themes were examined, a clear commonality was observed between "inclusiveness" and "communication". At the same time, a very low level of interaction

was found between the theme of "disability" and other themes. It can be said that the models exhibited inconsistencies in terms of ethical representation, giving weight to specific themes while relatively neglecting others.

## Pattern Consistency Analysis

In this study, pattern consistency analysis was conducted to evaluate the consistency of the responses given by large language models to ethical themes. The analysis was examined through metrics such as the average of the solution type, empathy level, solution consistency coefficient, and response frequency of the responses produced in different contexts within the scope of each ethical theme.

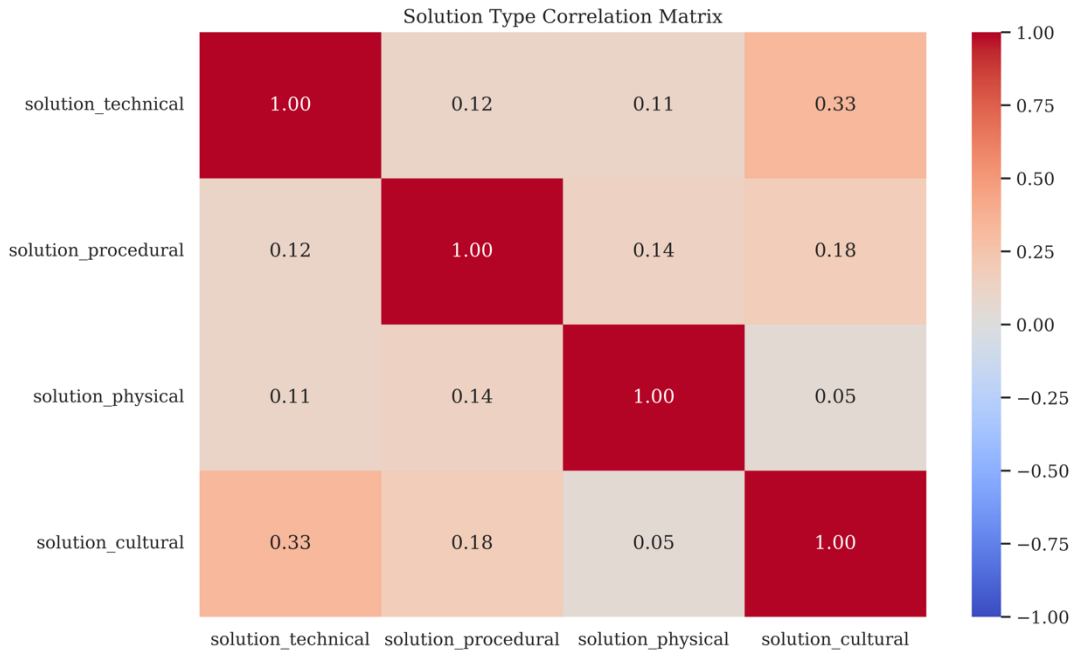


**Figure 2.** Solution type correlation matrix.

The findings indicate that there are theme-based inconsistencies in the way the models produce responses. For example, while the average solution score for the accessibility theme is 0.746 and the empathy level is 0.593, the solution consistency coefficient for the same theme is calculated as 1.244. Similarly, a moderate level of pattern consistency (0.996 and 1.008, respectively) was observed in the harmony and inclusiveness themes with relatively balanced solution and empathy scores. In contrast, the religious theme has the lowest consistency coefficient (0.706) with low average solution (0.33) and empathy (0.41) scores. This suggests that the model exhibits limited response quality and structural stability performance on this ethical topic. The theme of disability, on the other hand, attracted attention with its high response frequency (n=224), but remained at a moderate level in the resolution (0.536) and empathy (0.537) scores and presented a limited structural stability with a consistency coefficient of 1.016. The graphical presentation of these metrics can be observed in the graph in Figure 2, which visualizes the patterned similarities and variations between the themes. In general, the analysis reveals that the responses given by the

models to ethical themes differ not only in terms of content but also in terms of formal and emotional dimensions.

## Empathy and Linguistic Sensitivity Analysis

In this analysis, the level and forms of empathic expression patterns used by the major language models against ethical themes were examined in detail. The responses were coded under the subheadings of "support", "acknowledgment", "awareness", "validation", and "emotional care" according to the empathy categories. According to the graph in Figure 3, the most common empathic pattern was "awareness" (28.9%), followed by "validation" (24.7%) and "support" (20.4%). Emotional care expressions were observed at a rate of only 7.8%.

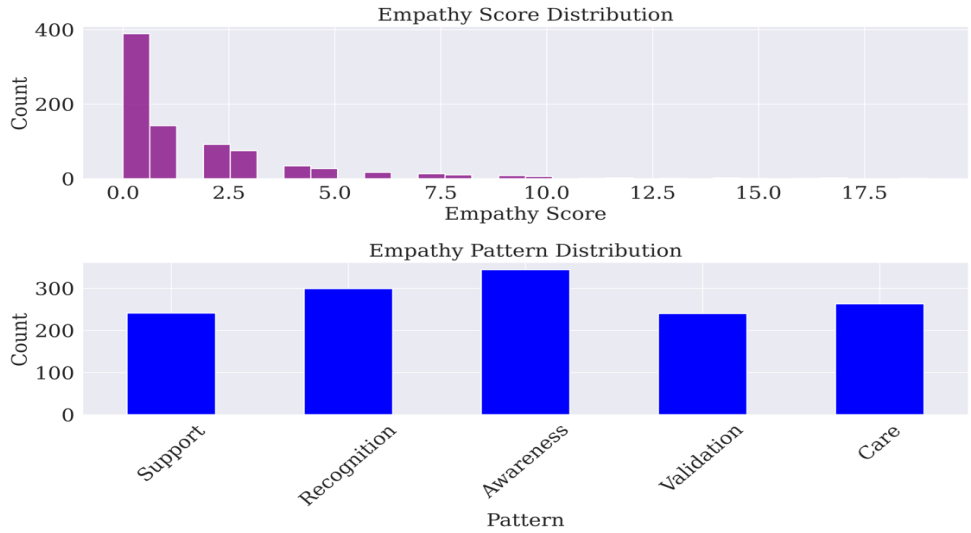


**Figure 3.** Empathy Score Distribution ve Empathy Pattern Distribution

In the image above, the empathy level displayed by the major language models in their ethical responses is presented under two headings. The upper graph, "Empathy Score Distribution", shows that the empathy score is concentrated at a low level (between 0 and 2) in most model responses. High empathy scores are rarely seen. The lower graph, "Empathy Pattern Distribution", shows the empathy patterns used. The most frequently used pattern is "Awareness", followed by "Recognition" and "Care". These findings show that the models adopt a more cognitive awareness-based approach in their empathic responses and prefer deep emotional expressions less.

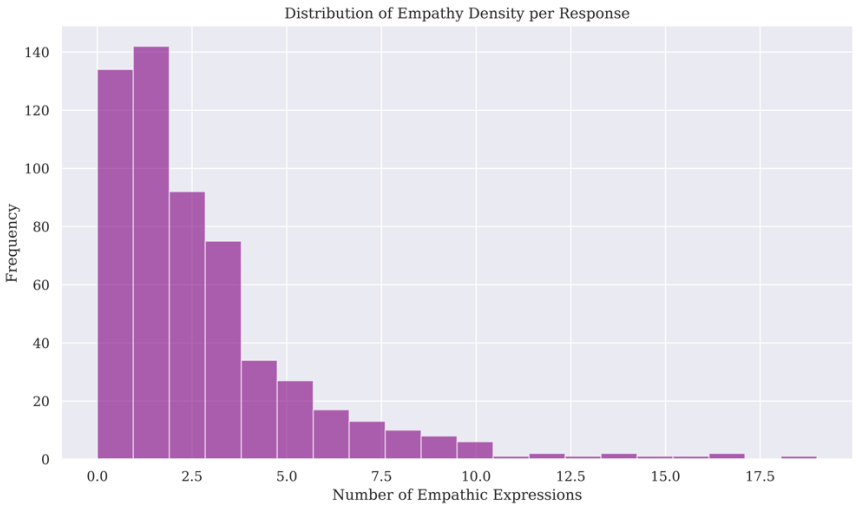


**Figure 4.** Empathy Density graph

This distribution reveals that language models tend first to understand and legitimize the situation (approve), then develop general warning or awareness (awareness) in empathizing. This approach shows that they present a more distant and objective empathy pattern rather than establishing a direct emotional relationship. When Figure 4 is examined, the average number of empathy expressions per response was calculated as 1.09, which went up to 13 in some responses. This situation shows that using at least one empathic element is essential in each model response, but the intensity of empathy can vary greatly depending on the theme and context.

The relationship between empathy levels and ethical themes is detailed with the Theme-Empathy Correlation graph in Figure 5. According to the findings, the highest average empathy scores were observed in the themes of respect (4.2/5), inclusiveness (4.0/5), and non-harming (3.8/5). On the other hand, the level of empathy appears to decrease in more abstract or normative themes such as autonomy (2.9/5) and neutrality (2.7/5).

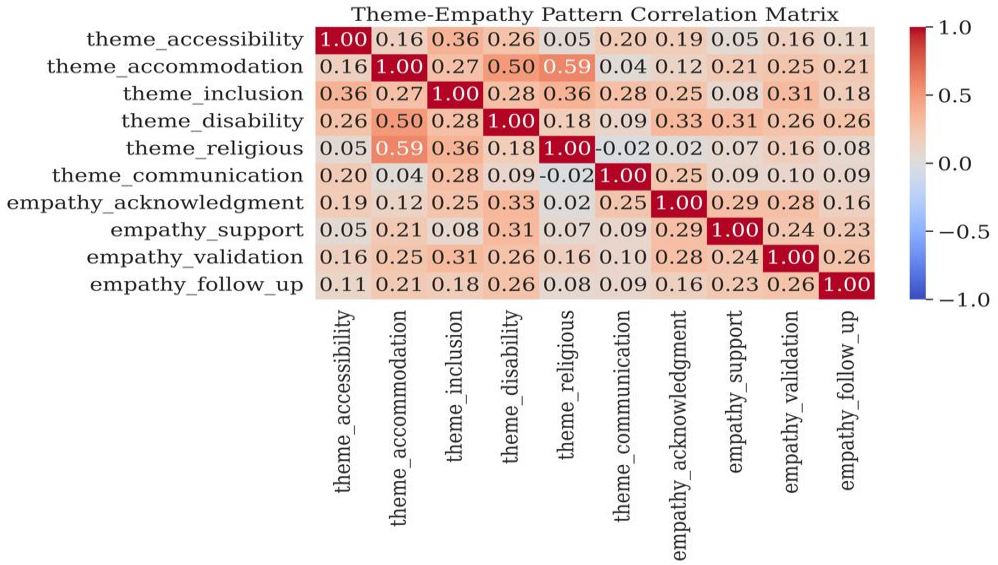

**Figure 5.** Theme-Empathy Pattern Correlation Matrix

This difference shows that the models are more prone to develop emotional sensitivity in some ethical themes, while adopting a more analytical and distant approach in others. The sample responses obtained in the qualitative analysis also confirm this difference. For example, in a response with the theme of inclusivity, the model used the following expression: “Developing supportive solutions for the equal participation of all individuals is very valuable; we can take steps together in this regard.” In contrast, in a response with the theme of impartiality, more objective language, such as “An impartial approach requires unbiased decision-making processes,” was preferred instead of empathy. These findings reveal that the models’ empathy styles are sensitive to the thematic framework but do not exhibit the same level of linguistic sensitivity in every ethical theme.

## Transition / Intersection Analysis Between Themes

The transition and intersection analysis between themes examines the tendency of large language models to refer to more than one ethical theme simultaneously in a single response (Figure 6. Theme Sankey graph and matching data reveal that the models frequently address ethical themes. A total of 1,548 theme matches were identified, with Inclusion + Communication (91 times) being the most frequently occurring theme pair, followed by Accessibility + Adaptation (72) and Adaptation + Inclusion (59). This shows a tendency for themes related to community and social contexts to be addressed together.

In the detailed analysis conducted according to the themes, it was seen that the theme of Inclusion was mentioned the most, with other themes with a total of 446 matches, suggesting that the model positions inclusivity as a central ethical theme. Similarly, the theme of Communication stands out with 369 intersections, and the high rate of these two themes together shows that the models mainly establish ethical sensitivity in the context of communicative content and community sensitivity. On the other hand, the fact that the theme of Disability was limited to a total of 33 matches shows that this area was handled relatively more isolated or limitedly in the model responses. These findings reveal that the models establish natural transitions between ethical themes while structuring others more independently.

## Inter-Scenario Contradiction / Context Change Analysis

Inter-scenario contradiction and context change analysis are critical in assessing the stability of model responses to ethical themes. The examination, especially on the theme of Disability, shows that the model is sensitive to contextual differences but has limited performance in terms of consistency Figure 7. According to the data, most of the responses given to the theme of disability were shaped in a supportive context (n=82). However, the fact that these responses also included complex (n=34), ambiguous (n=29), and even restrictive (n=15) content indicates that the model changes its ethical position according to the context.

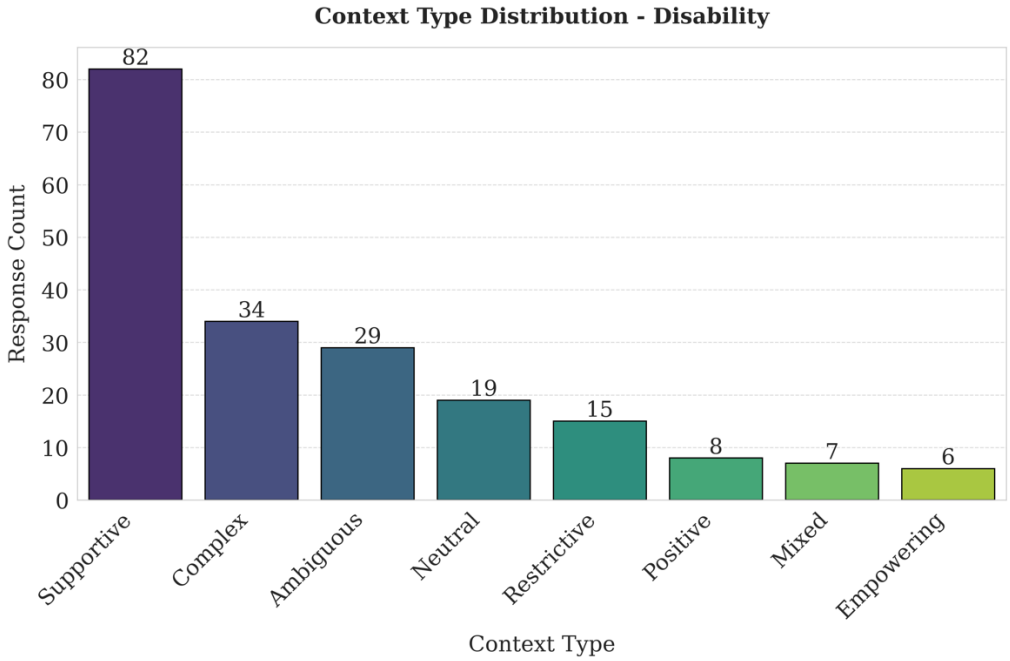


**Figure 7.** Distribution of Contextual Response Types to the Disability Theme

In one scenario, the model advocates for the autonomy and participation rights of individuals with disabilities, while in another scenario, it uses linguistic structures that may indirectly limit these rights. For example, while some texts contain empowering expressions such as "the system should be adjusted according to the needs of the individual," others contain deactivating structures such as "access to certain services may be limited." These contextual variations reveal that large language models contextually stretch ethical sensitivity; therefore, responses to the same theme may conflict contextually. This finding points to the importance of contextual control in training and guiding the model regarding consistent representation of ethical principles.

## Contextual Variation Analysis

Contextual Variation Analysis provides the opportunity to evaluate how the language model responds to the same ethical theme in different socio-cultural contexts. In particular, neutrality and accessibility may be addressed differently in religious, secular, institutional, or social environments. According to Figure 8, the theme of accessibility came up most intensively in social (n=69), health (n=27), and institutional (n=22) contexts, while it was processed more limitedly in religious (n=16) and secular (n=9) contexts. This shows that the model offers solutions for social sensitivity and the right to access in more collective contexts. On the other hand, the theme of disability was similarly processed more intensively in social (n=74) and health (n=37) contexts, but was emphasized relatively less in religious (n=11) and professional areas (n=8).

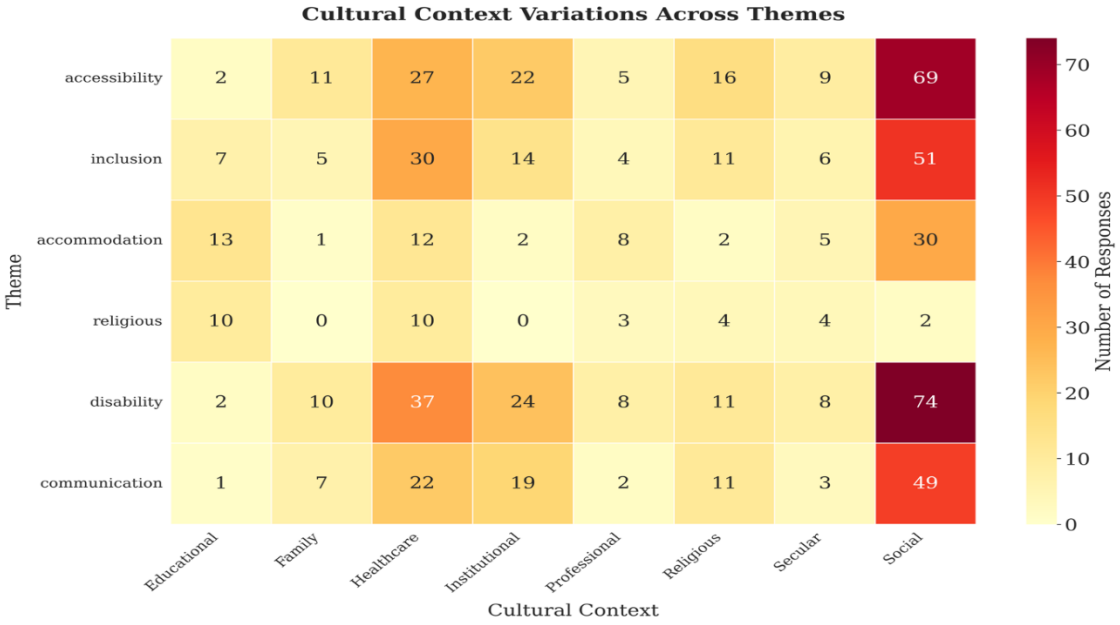


**Figure 8.** Cultural Context Variations Across Themes

The limited treatment of the religious ethics theme, especially in religious (n=4) and health (n=10) contexts, suggests that the language model exhibits a careful but superficial approach to cultural diversity. It was observed that the model tried to maintain neutrality in special religious scenarios such as Ramadan. However, the same theme was handled more systematically and normatively in the context of secular institutions. These differences indicate that the model's contextual awareness capacity is limited and that it sometimes produces responses that converge towards cultural blindness. This situation reveals the necessity of considering cultural diversity in ethical sensitivity and enriching the models with deeper contextual training. This systematic research questions whether large language models (LLMs) show consistency in ethical decision-making at thematic and contextual levels. The analyses conducted within the framework of three sub-research questions presented important findings at structural and normative levels. Thematic analyses conducted on the dataset revealed that models exhibited higher levels of empathy and solution determination in some ethical themes (e.g., “inclusiveness” and “accessibility”) (Braun & Clarke, 2019; Schramowski et al., 2022).

However, this performance was not equal for all themes. It was observed that the consistency coefficient was low, especially in specific themes such as “religion” and “disability”, and variable response patterns were produced depending on the context (Chiang et al., 2023). The Pattern Consistency Analysis partially answered this question positively. It was determined that the models responded with similar structural patterns in some themes (e.g., “harmony”, “inclusiveness”), and the average values were high in solution type and empathy level (Gabriel, 2020; Weidinger et al., 2022). However, there are significant differences in the pattern of variation across themes, indicating that consistency is not absolute but context-relative (Ji et al., 2023). The “Contextual Variation” and “Contradiction across Scenarios” analyses of the study revealed that responses to the same ethical theme in different contexts varied in terms of form and content (Floridi & Cowls, 2019). The theme of

disability was addressed with empowering language in one context and restrictive language in the other. This proves structural consistency is weak, although context sensitivity is high (Birhane et al., 2022). Empathy and linguistic sensitivity analyses provide findings that support this question. The number and type of empathy response patterns differ in the same ethical theme. For example, it is more objective in the "neutrality" theme and more emotional in the "inclusiveness" theme (Glaese et al., 2022). This shows that models produce structural pattern differences and that ethical consistency should be addressed beyond superficial similarity (Zhang et al., 2023). The main question and sub-questions of the research revealed that large language models have strengths and weaknesses in producing ethical responses; consistency, contextuality, and patterned structures vary according to the theme. This shows that the ethical orientations of the models are not fixed, but structures open to patterned diversity.

## DISCUSSION

Research findings show that the responses of large language models to ethical questions differ significantly at the thematic and contextual levels. In particular, the themes of "inclusiveness" and "communication" were the areas where the models most frequently provided empathic and solution-oriented responses (Gabriel, 2020; Zhang et al., 2023). In contrast, the themes of "religion" and "disability" were the weakest performance areas in terms of both response frequency and structural consistency (Chiang et al., 2023). Pattern Consistency Analysis revealed that the solution type adopted by the model, the empathy indicator, and the degree of structural stability changed under each ethical theme. This shows that the models were more sensitive and systematic to specific themes, and superficial and variable in their responses to others (Ji et al., 2023; Birhane et al., 2022). The identified inconsistencies in AI ethical responses parallel challenges observed in human-centered management systems, where sustainable practices must balance multiple stakeholder interests and ethical considerations (Vovk & Vovk, 2024). These patterns suggest that consistent application of ethical principles requires systematic integration into operational frameworks and continuous monitoring across different contexts. The transition analyses between themes revealed that the models addressed some ethical principles together and evaluated others in isolation. For example, while the themes of "inclusivity" and "communication" were frequently patterned together, abstract normative themes such as "neutrality" were often processed alone (Floridi & Cowls, 2019; Weidinger et al., 2022). Contextual Variation Analysis showed that the model responded to the same theme with different content in social, religious, or institutional contexts. Discursive contradictions, especially seen in disability-themed responses, prove that the model can change its ethical position contextually (Srivastava et al., 2022; Raji et al., 2020). These findings largely support the main question and hypothesis of the research. It was concluded that LLMs can establish superficial semantic similarity, but show significant variability in thematic and structural ethical consistency (Binns, 2018; Hooker & Kim, 2019; Ganguli et al., 2023). This variability shows that the normative consistency capacity of the models is limited according to the context and theme.

The study's findings confirm some studies in the literature and critically complement others in that they reveal that large language models do not consistently produce ethical

responses and exhibit contextual variations at the thematic level. For example, Glaese et al. (2022) showed that models trained with human feedback can give more ethically acceptable responses. However, this study observed that the model changed its ethical position as the context changed; this suggests that consistency cannot be reduced to user feedback alone. Similarly, Tamkin et al. (2021) stated that LLMs provide normative consistency only under narrow samples and limited scenario sets; this study showed that contextual differences were decisive in a wider thematic range. Bender et al. (2021) argued that large language models multiply biases in the training data, and therefore, their responses are far from being ethically diverse. This study identified pattern weaknesses supporting this thesis, especially in the themes of "religion" and "disability". It is seen that the ethical alignment strategies proposed by Askell et al. (2021) were developed without taking contextual diversity into account. This study made a critical contribution to this approach by revealing that artificial intelligence systems rearrange their normative positions in different contexts. Zhou et al. (2023) found that LLMs give contradictory answers to the same ethical principle in different contexts. This study reached a similar conclusion with scenario-based analysis. However, it increased the depth of analysis and showed that contradictions occur not only at the content level, but also at the linguistic and discursive level. Santurkar et al. (2023) drew attention to the problem of cultural context blindness; this study conducted cultural diversity tests empirically. While Bommasani et al. (2021) examined model outputs only in the context of performance and accuracy, this study brings a new approach to the literature to evaluate ethical sensitivity through structural patterns.

This study has presented an original theoretical framework to the literature by evaluating the ethical sensitivity of large language models at the content level based on thematic patterns and contextual transitivity. First, redefining ethical consistency as a structural concept emphasizes the importance of "what is said" and "how and in what structure" it is said. This represents a methodological shift from content-intensive assessments to formal analyses in the AI ethics literature (Andrus et al., 2021; Floridi et al., 2018). Second, the study has enabled multi-layered ethical interpretation of AI outputs by associating the "thematic pattern" concept with coding-based qualitative analysis (Vaismoradi et al., 2016). One of the theoretical contributions of the study is that it integrates the concept of context sensitivity into ethical response analysis. Thus, it has been shown how LLMs interact with ethical priorities that change according to context, not only within the framework of fixed rules. In addition, the discourse-based approach, which analyzes how discourse forms differ in model outputs, has revealed how ethical tendencies are represented by formal language patterns in language production (Mokander & Floridi, 2021; Weidinger et al., 2022). Methodologically, this study developed a hybrid model that integrates qualitative coding with numerical analyses based on big data. This approach provided high-level explanatory power not only in terms of sample generality but also in terms of data diversity (Saldaña, 2021). It stands out as one of the rare studies in the literature that systematically examines ethical responses through empathy patterns. At the policy level, these findings allow ethical regulation processes to be reconstructed based on thematic coherence in artificial intelligence systems. In practice, it is suggested that process-oriented pattern analyses should support ethics training modules, not only outcome-oriented (Ji et al., 2023; Gehrmann et al., 2023). In terms of empirical research, this study provides a theoretical starting point for developing ethical assessment models sensitive to different cultural contexts.

The results of this study offer important practical implications for evaluating the ethical performance of large language models and integrating them into application areas. The findings regarding thematic inconsistencies in AI ethical responses align with challenges observed in implementing AI-driven technologies in transport logistics, where the adoption of artificial intelligence for route optimization and decision-making requires careful consideration of ethical frameworks and consistency measures (Vovk et al., 2025). It is seen that artificial intelligence-based assistant systems used in clinical and professional practices, especially in patient-physician, client-therapist, or student-instructor interactions, need ethical guidance (Topol, 2019). In this context, artificial intelligence systems should not be used in critical decision support systems without testing their ethical sensitivity level (Raji et al., 2020). Regarding education and awareness programs, it is not enough to convey ethical principles only at a theoretical level. This study shows that educational simulations can be structured on a contextual rather than content-based basis using the pattern differences seen in LLM outputs. This allows for developing dynamic and model-based scenarios in university ethics courses or corporate training (Anderson & Rainie, 2020; Jobin et al., 2019). In the context of intervention and prevention strategies, it is necessary to develop filtering and automatic error correction mechanisms by considering the potential for "ethical misdirection" in artificial intelligence systems. It is necessary to monitor not only what the models say, but also on which theme and with what consistency. This is of vital importance in terms of algorithmic transparency and accountability principles (Binns et al., 2018; Gabriel, 2020). The contextual variability of ethical decisions becomes particularly evident in autonomous systems applications, where AI technologies must navigate complex urban environments and make real-time decisions affecting public safety and urban planning (Razavi & Sierpinski, 2024). In technology use policies, ethically based control mechanisms should be prioritized. It has become a necessity for institutions to evaluate LLM-based systems not only in terms of functionality but also in terms of value representation (Birhane et al., 2022; Floridi & Cowls, 2019). In psychosocial support systems, themes where empathy patterns can be produced to a limited extent should be taken into consideration, and human control should be strengthened in these areas.

Some limitations of this study may have restrictive effects on the generalizability of the findings. First, since the dataset used focuses on specific ethical themes (accessibility, inclusiveness, disability, communication), it does not represent all ethical principles. This situation has led to the analysis being limited to specific themes. In addition, the model responses are based only on textual outputs, and the impact of these responses on the user or their social perception has not been tested; therefore, behavioral validity is limited. This situation has prevented an in-depth analysis, especially in discussions of cultural context blindness. In addition, the fact that the cross-effects between the ethical themes used in the analysis could not be sufficiently separated in some contexts has increased the effect of confounding factors. In terms of methodology, relying only on thematic analysis and descriptive statistics has limited the possibility of making quantitative comparisons. Finally, an external set of criteria that can make a normative assessment of ethical consistency has not been developed. This also creates a limitation in interpreting the ethical validity of structural patterns.

In future studies, the ethical consistency of large language models should be tested comparatively in different cultural, linguistic, and socio-economic contexts. Multilingual

analyses are recommended, especially assuming that normative frameworks are not universal but culturally constructed. In order to improve research results, broader data sets and comparative assessment of both textual and behavioral outputs are necessary. Policymakers should not limit ethical regulations in AI systems to algorithmic auditing alone; they should also include discursive consistency in outputs in regulatory frameworks. Institutions should conduct ethical competence tests before using LLM-based tools, and ethical risk training should be mandatory for employees. Practitioners should develop guide protocols to audit context sensitivity in model outputs manually. Within the framework of intervention and prevention strategies, monitoring systems that detect ethical deviations should be designed; these systems should be supported by human auditing. In the field of education, AI ethics courses should be strengthened not only with technical knowledge but also with scenario-based awareness studies.

## CONCLUSION

This study presents a qualitative analysis that questions the structural consistency of large language models in ethical decision-making based on thematic patterns and contextual diversity. In today's world, where artificial intelligence systems are rapidly integrating into human-centered areas, it is clear that these systems should be evaluated in terms of technical competence and compliance with ethical norms. In this context, the study's primary purpose was to reveal the extent to which the responses of large language models under different ethical themes carry normative integrity and contextual stability. The research showed that LLMs exhibited high empathy, solution stability, and linguistic sensitivity in some themes (e.g., inclusiveness and communication). At the same time, ethical consistency was weak in some themes (especially religion and disability). The frequency of transitions between themes and pattern consistency varied in different contexts, which revealed that ethical decision-making was not fixed but contextual. In scenario-based analyses, it was observed that responses belonging to the same ethical principle shifted in meaning as the context changed and consistency problems occurred. In addition, it was observed that empathy patterns were concentrated in some themes, while they remained weak and superficial in others. These findings reveal that AI systems carry content and structural diversity in producing ethical responses. This study has made an original contribution to the literature by analyzing ethical consistency with a pattern-based approach. This approach, which emphasizes that ethical evaluation processes should be process-oriented rather than outcome-oriented, reveals that linguistic and discursive structures in LLM outputs should also be controlled.

Findings were obtained theoretically, supporting the assumption that ethical decisions are shaped not by fixed norms but by contextual sensitivities. The results of the study offer important implications for various stakeholders. Researchers should expand the ethical performance of LLMs in different cultural and socio-political contexts with comparative analyses. Policy makers should institutionalize normative consistency tests in AI regulations and apply ethical control mechanisms to algorithms and outputs. Practitioners should only put AI systems into operation in areas that pose ethical risks (health, education, public administration) after ethical compliance tests. Educational institutions should address the issue of AI ethics not only technically but also within the framework of ethical discourse

patterns and context sensitivity; they should develop awareness modules in this area. This study has revealed that ethical decision-making processes should be examined at a principled, contextual, and structural level for individuals and learning machines. As the impact of AI on human life deepens, the decision structures of these systems will inevitably be designed in a transparent, consistent, and human-dignified manner. The fact that ethical consistency is not only a moral demand but also a technological necessity has been emphasized once again by this research.

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# ADAPTING TO THE DIGITAL AGE: GAMIFICATION'S ROLE IN REVOLUTIONIZING EDUCATION FOR YOUTH STUDENTS

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Abstract: *Gamification, an educational strategy incorporating game-based elements, is gaining traction. Using the Unified Theory of Acceptance and Use of Technology model constructors, this study examines the adoption of gamification among 350 university students, which is representative of gender. The findings reveal a strong positive correlation between performance expectancy, and hedonic motivation, highlighting the role of gamification in fostering intrinsic motivation among learners. Most of all, the learning value influences behavioural intention directly in students thus consistently prioritising higher expected knowledge gains regarding performance, time invested, and energy expended. Overall, the study demonstrates the significance of several UTAUT constructs, including performance expectancy, effort expectancy, self-innovation, and hedonic motivation, in influencing the propensity to adopt gamification in educational settings. This research contributes to a deeper understanding of gamification's potential to enhance student engagement and learning outcomes, particularly among younger generations accustomed to interactive and engaging digital experiences.*

Keywords: *Gamification, higher education, CFA, intrinsic motivation, learning value*


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## INTRODUCTION

The rapid development of modern technology and the evolving learning preferences of new generations have brought about significant educational changes. Young people are now accustomed to digital technologies from an early age and use them naturally in their daily lives. There is an increasing demand to innovate traditional methods and effectively use technology to support learning in school and university environments (Groff, 2014; Moyle, 2010). Gamification offers a promising approach to enhance student engagement and motivation, often considered challenges in traditional education settings. Teachers increasingly explore gamification strategies to create more dynamic and interactive learning experiences. However, some teachers may have concerns about integrating gamification into their lessons, fearing that it may distract from the learning objectives or not be appropriate for all subjects (Alsawaier, 2018; Adams, Du Perez, 2022; Kim, 2015).

Gamification can bring several benefits to the learning process, including Increased student engagement and motivation, improved comprehension and knowledge acquisition, more straightforward understanding of complex concepts, and enhanced self-regulation skills. However, gamification has potential drawbacks, such as overemphasising game elements, potentially detracting from the learning goals and requirements for significant design and development resources. Due to various concerns, some teachers may hesitate to incorporate gamification into their teaching. These usually lack familiarity with gamification concepts and techniques and fear of compromising their lessons' rigour and academic quality (Chans, Portuguez Casto, 2021).

In higher education, several studies have reported on gamification's confusing or ineffective existence, and concerns about the areas in which it can be used are also mentioned. Gamification can be effectively applied in various areas of higher education. Supporting professional practice and project-based learning, teaching business and commercial subjects, and enhancing individual learning goals and objectives (Langendahl et al., 2016; Jääskä, Aaltonen, 2022). This research aims to explore the interrelationships between some of the constructs of the UTAUT technology adoption model, focusing on the elements of intrinsic motivation. The UTAUT model is a widely used framework for understanding the factors influencing technology adoption behaviour. The research seeks to answer the following research question (RQ):

- *RQ: How does hedonic motivation, expected learning, performance expectancy, and effort expectancy (the desire for enjoyment and engagement) affect the behavior intention to use gamification?*

This research aims to contribute to a deeper understanding of the relationship between gamification and intrinsic motivation, which can inform the effective implementation of gamification in educational settings. The findings of this research can help teachers and developers design and implement gamification strategies that effectively motivate students and enhance their learning experiences, primarily in higher education.

## LITERATURE REVIEW

### Definition and evolution of gamification

To understand the concept of gaming, it is important to understand the difference between the words "playing" and "gaming". The word "playing" refers primarily to a child's activity, which takes place in a spontaneous, self-indulgent state. The word "gaming", on the other hand, is more associated with games, which are usually governed by rules and objectives (Santayana, 1955; Caillois, 1961). The word "game" means a purposeful activity governed by rules, the outcome of which is determined by numerically determined points, such as winning or losing. Deterding et al. (2011a) have represented this in a two-by-two matrix, which illustrates how the application of each element affects the completeness of the game.
The concept of gamification emerged in the early 2000s and has been evolving ever since. The term was first coined in 2002 by the British game developer Nick Pelling, who defined it later in a 2011 article as the game-like user interface of electronic devices and the making of them more enjoyable and fast (Pelling, 2011).

However, the first real conceptualization was later, when in a conference presentation Deterding et al. (2011b) defined it as "the use of playful, game design elements in a non-game environment", i.e. the transposition of something into a different context.
Since Deterding's definition, a number of other experts have articulated the concept of gamification.

**Some of the most common definitions are presented below:**

- As stated by Sweetser & Wyeth (2005), gamification is *"the design process of applying elements and principles from games to other contexts"*.
- Deterding et al. (2011a) describe gamification as *"the application of the scientific study of playfulness to non-game environments"*.
- According to Kapp (2012), gamification is *"the transposition of game elements and mechanisms into non-game environments in order to motivate, engage and induce learning, performance or other desirable behaviours"*.

Zichermann & Cunningham (2011) wrote that the purpose of its application is to achieve some behavior. At the same time, it is emphasized that game design thinking and the use of certain game mechanisms can be successful in involving users. The definition of Werbach & Hunter (2020) does not differ much from the previous one, they also detail the game elements and their insertion into the context, but they emphasize that there will be no gamification by packing a few game elements one behind the other in a foreign environment. After that, Kapp examined its role in education. Based on his wording, the focus was on game-like, game design organization and implementation, where the goal was to motivate people, engage them and encourage them to take action, to overcome problems effectively (Kapp, 2012). When creating the term, Finnish researchers Kai & Juho (2016) focused on practical experiences, writing about processes where the individual gets a game-like experience when using certain services

(Kai & Juho, 2016). According to Pusztai (2020), gamification is a strategy where game elements are used in a non-gaming environment to move users' behavior in a positive direction.

The emergence of the concept of gamification has also varied in time and space. The concept has spread primarily in the United States and Europe but has gained popularity in other countries in recent years like in Latin America and the Caribbean (Dodi, 2020). Gamification is used in a wide range of fields, such as marketing, education, healthcare and corporate environments. The concept continues to evolve and is expected to play an increasing role in society in the future.

**The development of the concept of gamification can be divided into the following stages:**

- The beginning (2002-2011): During this period, the concept was not yet fully developed and was defined differently by different experts.
- The conceptual development (2011-2015): During this period, the definition of gamification by Deterding and his colleagues became the most widely accepted.
- The spread (2015-present): Since then, gamification has gained popularity and is being applied in a wide range of fields (Pelling, 2011).

The future of the concept of gamification is still uncertain but is expected to continue to evolve. The success of the concept may depend on some factors. the growing popularity of video games, coupled with a better understanding of game design elements and mechanisms, is driving the adoption of gamification. As technology continues to advance, gamification will become more accessible and effective, enabling its widespread implementation in various sectors like tracking human bio-physiological activities by Virtual Reality (VR) (Wojciechowski et al., 2021). With these factors in place, gamification is poised to play an increasingly significant role in shaping the future of human interaction and behavior.

## Using gamification in higher education and elsewhere

Gamification is an increasingly popular method in marketing, human development and education (Brzozowska et al., 2024; Kapp et al., 2014; Kozová et al., 2024). The word is a combination of the English words “game” and “fication” (Nakashima et al., 2017). While the concept is not yet fully defined, it is generally understood to involve the application of game elements in a non-game environment (Deterding et al., 2011b).

The aim of gamification is to motivate and engage people in a particular activity. Playful elements such as points, levels, tasks and rewards can make the activity more enjoyable and improve performance. Over the last fifteen years, gamification has enjoyed international success, particularly in marketing. Motivational theories and psychological tests demonstrate that individuals have diverse intrinsic needs. In order to satisfy these needs and motivate people, different incentives are required, such as rewards and recognition. Play and playfulness have been part of our lives since the dawn of mankind, and it is precisely because of their ancient nature that we can use them for both intrinsic and extrinsic motivation. Gamification uses these motivational factors to encourage the completion of specific tasks based on needs

and desires. The gamification of certain organisational tasks can also positively impact engagement and work morale (Hammedi et al., 2021). When people find a task exciting, they are eager to complete it, which positively affects productivity and teamwork (Kapp et al., 2014; Samoliuk et al., 2021; Vegt et al., 2018).

Gamification is used as an incentive at all levels of education and development. However, an article has already been published on the potential of using digital environments and game-based methods to support rehabilitation in ageing (Wojciechowski & Korjonen-Kuusipuro, 2022). Its use has been demostrated from early childhood (Mikó 2018; Hossein-Mohand et al., 2021; Carvalho et al., 2015; Huizenga et al., 2009; Schwabe & Göth, 2005) through to secondary school, in areas such as reading and other skill development (Ronimus & Lyytinen, 2015; Njå, 2020), language learning (Gooch et al, 2016; Garcia, 2013; Huynh et al, 2016), and music and art education (Szabó, 2018).

Examples of gamification can also be found in higher education. In addition to the gamification of courses (Barabási, 2020; Pusztai, 2020; Bicen & Kocakoyun, 2017), a few case studies on the subject have been published. However, it is important to note that maintaining motivation is highly valued in higher education. Many lecturers belong to Generation X, while their students belong to Generation Z (Maczó, 2019). The differences in motivation and communication between these two groups can result in tensions, a topic previously explored by Prievara (2018). Kenéz (2016) points out this method can be applied in many areas of higher education, including during lessons, examinations and home learning, which can play a prominent role in the current online education context. The most commonly used game elements are point systems, teamwork, and quizzes and tests that measure classroom activity. Multimedia elements, bonus tasks, and avatars also take advantage of certain e-learning systems (Bernik et al., 2017; Kurucz & Gajzágó, 2019; Kiryakova et al., 2014). It is no coincidence that Kahoot!, Quizizz, Socrative or the flipped classroom approach have been incorporated into most digital learning tools (De La Cruz et al., 2023). Furthermore, the use of gamified applications has been studied in university settings, where researchers have obtained positive results in promoting deep learning. They have noted that such solutions are well received by students and can promote a student-centred approach, strengthening the university brand (Aguiar-Castillo et al., 2021).

## The model constructors

Today's world is characterised by constant innovation, renewal and technological development, complemented by continuous improvement and accelerated data exchange (Bartuseviciene & Butkus, 2024; Bilan et al., 2023). Different technology acceptance models are a critical part of technological innovation, as testing the model can provide answers to the reception, perception and failures of your innovation. The justification of these models has been supported by a number of studies over the years (Blut et al., 2016; King & He, 2006; Korcsmáros et al., 2025; Jeroen & Wetzels, 2007). The following is a brief description of the model variables used. The research did not examine other potential moderating variables, such as religion, moral norms or culture.

## Performance expectancy (PE)

In the UTAUT (Unified Theory of Acceptance and Use of Technology) model, performance expectancy refers to the expectation that the use of a technology will help the user achieve their goals. It is one of the four key constructs that influence an individual's intention to use technology, along with the expectation of effort, social influence and enabling conditions.

Performance expectancy is essentially an evaluation of the perceived usefulness of technology. A user with a high-performance expectancy believes that using technology will lead to positive outcomes, such as improved productivity, increased learning, or increased task satisfaction. This belief is influenced by several factors, including the user's previous experience with similar technologies, the perceived ease of use of the technology, and the availability of training and support (Venkatesh et al., 2003).

A strong expectation of performance is crucial in encouraging technology adoption. If users believe that technology can help them achieve their goals, they are more likely to be motivated to use it and to persevere despite any challenges they may encounter.

Performance expectancy can be influenced in the context of gamification by providing users with clear and achievable goals, timely and relevant feedback along with rewards for progress, and incorporating challenges and opportunities for skill development. By effectively addressing performance expectancy, gamification can significantly increase the likelihood of user adoption and engagement. By effectively addressing performance expectancy, gamification can significantly increase the likelihood of user adoption and engagement, as several studies have already pointed out (Ofosu-Ampong, 2019).

## Effort expectancy (EE)

Effort expectancy is influenced by several factors, including the user's prior experience with similar technologies, the perceived complexity of the technology, and the availability of training and support (Venkatesh et al., 2003). A strong effort expectancy can lead to increased user adoption and engagement, as users are more likely to be willing to try out and use technology if they believe it will be easy to learn and use. A user with high effort expectancy believes that using the technology will not be difficult or time-consuming to learn and use. They may also believe that the technology is straightforward to navigate and that they will be able to find the information or support they need when they need it.

Gamification can effectively manage effort expectancy by employing an intuitive and user-friendly interface, meticulously crafted instructions and tutorials, and a comprehensive support system encompassing help guides, FAQs, and vibrant community forums. These measures collectively contribute to a gamified system that is readily accessible and less cognitively taxing, thereby fostering enhanced user engagement and satisfaction (Kyewski & Kramer, 2018).

**Self-innovation (SIN)**

Self-innovation is a relatively new construct that has been proposed as a potential fifth construct in the UTAUT model (Attié & Meyer-Waarden, 2022). Self-innovation refers to a person's tendency to embrace and adopt new technologies, even those that are perceived to be risky or challenging.

The inclusion of self-innovation in the UTAUT model suggests that a user's willingness to adopt a technology may also be influenced by their personal disposition towards innovation and risk-taking. A user with high self-innovation is more likely to be willing to try out new technologies, even if they are unsure of the benefits or potential drawbacks.

A study by Venkatesh et al. (2012) found that self-innovation was a significant predictor of user adoption of social media platforms. The study also found that self-innovation was positively correlated with other UTAUT constructs, such as performance expectancy and effort expectancy.

**Learning value (LV)**

The learning value item is a significant predictor of technology adoption in a variety of settings, including educational settings, corporate training programs, and online learning platforms. This suggests that the perceived usefulness of a technology for learning is an important factor in influencing user behaviour. High scores on the learning value item indicate that the user believes that the technology is useful for learning and skill development. This belief can then influence the user's intention to use the technology and their actual usage behaviour (Sitar-Taut & Mican, 2021).

Infusing learning with game-like elements, such as points, badges, and levels, can transform the learning process into an engaging and motivating experience. Secondly, establishing clear and achievable objectives can empower learners to stay focused and maintain direction throughout their learning journey.

Thirdly, timely and relevant feedback plays a crucial role in guiding learners, enabling them to identify areas for improvement and track their progress effectively. Finally fostering collaborative and competitive environments can transform the learning experience into an engaging and motivating environment, where the users collaborate to achieve shared goals and compete with peers to enhance their skills and knowledge.

**Hedonic motivation (HM)**

Hedonic motivation is essentially the intrinsic reward associated with using a technology. A user with high hedonic motivation find using the technology to be enjoyable and engaging, and they derive pleasure from interacting with the technology itself. This motivation is often driven by factors such as the aesthetic appeal of the technology, the sense of challenge and accomplishment, and the social interactions it facilitates.

Hedonic motivation is influenced by several factors, including the user's personality, their prior experiences with similar technologies, and the overall design and functionality of the technology. A strong hedonic motivation can lead to increased user adoption and engagement,

as users are more likely to be willing to use a technology if they believe it will provide them with enjoyment and satisfaction (Oluwajana et al., 2019).

Immersive design can transform gamified systems into captivating experiences that foster hedonic motivation. By creating a stimulating and engaging user interface, gamification can enhance user enjoyment and motivation (Shahzad et al., 2023). Game-like elements, such as points, badges, and levels, can provide users with a sense of progress and accomplishment, further fueling hedonic motivation. These rewards offer tangible and visible indicators of achievement, reinforcing engagement and satisfaction. Incorporating variety and challenge into gamified systems helps prevent boredom and disengagement, thereby keeping users actively engaged. Gamification caters to different interests and preferences by introducing a diverse range of tasks, challenges, and experiences, ensuring a continuously engaging experience. Gamification taps into the human desire for enjoyment and satisfaction by examining hedonic motivation. Gamification makes technology more attractive and usable by engaging the user and creating rewarding and intrinsically motivating experiences (Venkatesh, 2012).

## METHODOLOGY

### Data and Sampling

Altogether 350 responses were gathered using snowball sampling with the help of the student council of the Faculty of Business and Economics between 2021 and 2022. The sample can be considered representative concerning gender according to the results of Graduate Career Tracking System (GCTS, 2022) for full-time students (GCTS, 2022). The survey consisted of 8 blocks of indicators measuring the advantages (Pros), disadvantages (Cons), PE, EE, LV, SIN, HM, BM of using gaming in education.

### Applied methods

At the first stage of the analysis and model construction, a Confirmatory Factor Analysis (CFA) was applied to test construct consistency with its indicators (how well were the indicators described by their constructs). During this process, some indicators were left out of the model due to the lower loadings (the threshold was 0.4). Originally, constructs „Pros" and „Cons" contained 7 indicators, respectively, while PE and EE contained 4 indicators, respectively. In the final theoretical model, each construct consisted of only 3 indicators. Factor reliability and inner consistency were measured through McDonald's omega (McDonald, 1999) and Cronbach's alpha. The reason for reporting even omega was that the (equal factor loadings, uncorrelated errors) of Cronbach's alpha are very restrictive and often violated (Hayes & Coutts, 2020). On the other hand, the factorial scores were utilized in the present study and omega was specially developed for a factor model using the square of the sum of the factor loadings (McDonald, 1999). In the second stage of the model building, an Explanatory Factor Analysis (EFA) was employed to establish the appropriate latent constructs with the relevant indicators. For the factors score estimation, Thurstone's regression (Thurstone, 1934) method was used. Factor extraction was performed by using the minimum residuals method.

In the final stage of the analysis, K-means (using Hartigan-Wong, MacQueen and Forgy algorithms) and hierarchical cluster analyses were performed on the CFA constructs. MacQueen's K-means clustering with 5 clusters was used to produce the final clustering. The optimal number of clusters was determined by using the so-called gap statistic. The cluster characteristics and differences then were examined using a Chi-squared test for gender, age and place of residence, presented in a bar chart.

The goodness of the CFA model fit was measured by Chi-squared test, Tucker-Lewis index (TLI) (Tucker & Lewis, 1973), comparative fit index (CFI) (Bentler, 1990) and the root mean squared error of approximation (RMSEA) (Stiger, 1990). The threshold for TLI and CFI was 0.9, higher values indicate a good model fit. On the other hand, a lower than 0.08 value for RMSEA indicates a proper model fit. Effect sizes were measured for chi-squared test with the effect size index (w), which is the square root of the quotient of chi-square value and the number of cells in the crosstable. Silhouette index (Rousseeuw, 1987) was used for measuring and comparing cluster quality. Jamovi 2.4.8. software (Jamovi project, 2023) was used to perform all analyses in the study. This software uses R statistical software (R Core Team, 2022) and its packages. The „lavaan" package (Rossel, et al., 2023) was used to fit CFA, package „psych" (Revelle, 2023) was used for creating the factors and performing an EFA analysis, „snowCluster" package (Seol, 2023) was used to cluster data according to the established CFA construct. The authors also used the R script capabilities of Jamovi to calculate the Silhouette index using the „cluster" package.

## EMPIRICAL RESULTS

### Results

This study sought to ensure a representative sample with regards to gender distribution, aligning with the findings of the Global Citizenship Test Survey (GCTS, 2022). Their research on the entire University of Debrecen student population indicated a 62.5% composition of women. In mirroring this statistic, our sample achieved a comparable proportion of female participants, bolstering the overall representativeness in terms of gender composition.

**Table 1.** Distribution of the sample across gender, age and place of residence

| Gender | Counts | % of Total |
|---|---|---|
| Male | 137 | 39.1 % |
| Female | 213 | 60.9 % |
| **Age** | | |
| Under 20 Years | 105 | 30.0 % |
| 20, 21 Years | 127 | 36.3 % |
| Over 21 | 118 | 33.7 % |
| **Place of residence** | | |
| Village | 90 | 25.7 % |
| City | 159 | 45.4 % |
| County town | 101 | 28.9 % |

*N=350*

[Source: Authors' Calculation.]

*: all Z-statistics were statistically sigificant at 99.9% level of confidence (p<0.001)

Furthermore, to guarantee approximate proportional representation across age groups, we meticulously constructed categories that encompassed similar student numbers within each respective range. This approach mitigates potential biases arising from overrepresentation or underrepresentation of specific age demographics, contributing to the robustness of our sample.

Finally, we acknowledged the potential impact of geographic origin on student characteristics and perspectives. Consequently, our sample aimed to reflect the distribution of urban, county town, and village residents within the broader student population. City residents constituted almost half of the sample, while approximately a quarter of students were from county towns and villages, respectively.

**Table 2.** Loadings and major descriptive statistics of the indicators used in the CFA model

| Factor | Indicator description | Loadings** | Standard Error | Z-statistic* | McDonald's omega (Cronbach's alpha ) | $\bar{x}$ | Standard deviation |
|---|---|---|---|---|---|---|---|
| PROS | PRO1. arouses my interest | 0.810 | 0.044 | 16.8 | 0.812 (0.808) | 4.21 | 0.91 |
| | PRO2. motivate | 0.757 | 0.049 | 15.3 | | 3.85 | 0.99 |
| | PRO3 increase my activity in class | 0.736 | 0.052 | 14.8 | | 3.95 | 1.04 |
| CONS | CON1. distracts me from the lesson | 0.745 | 0.043 | 14.7 | 0.808 (0.795) | 1.98 | 0.97 |
| | CON2. I can't concentrate on the subject | 0.717 | 0.058 | 13.5 | | 1.77 | 0.85 |
| | CON3. frivolous to me | 0.828 | 0.048 | 16.5 | | 1.96 | 1.08 |
| PE | PE1. I find useful in higher education | 0.871 | 0.040 | 20.2 | 0.873 (0.865) | 4.07 | 0.93 |
| | PE2. improves learning efficiency | 0.896 | 0.038 | 21.1 | | 4.08 | 0.90 |
| | PE3. asks can be completed faster | 0.733 | 0.047 | 15.6 | | 3.90 | 1.01 |
| EE | EE1. I see through the method | 0.727 | 0.046 | 14.0 | 0.730 (0.722) | 3.76 | 1.05 |
| | EE2. no more difficult to master | 0.783 | 0.044 | 15.3 | | 4.17 | 0.90 |
| | EE3. easy to use | 0.703 | 0.055 | 13.4 | | 4.16 | 0.85 |
| SIN | SIN1. try new things immediately | 0.711 | 0.064 | 13.6 | 0.769 (0.764) | 3.56 | 1.22 |
| | SIN2. be the first among my friends to try new technology | 0.684 | 0.067 | 12.9 | | 3.14 | 1.27 |
| | SIN3. experimenting with new technologies | 0.779 | 0.058 | 15.1 | | 3.59 | 1.12 |
| LV | LV1. control my learning time | 0.764 | 0.056 | 16.3 | 0.844 (0.837) | 3.39 | 1.19 |
| | LV2. expand my knowledge and strive to succeed | 0.842 | 0.045 | 18.9 | | 3.77 | 1.02 |
| | LV3. I learn the material immediately and easily | 0.809 | 0.044 | 17.7 | | 3.80 | 0.97 |
| HM | HM1. fun and interesting | 0.869 | 0.039 | 20.1 | 0.904 (0.896) | 4.23 | 0.91 |
| | HM2 happy to use | 0.919 | 0.037 | 22.1 | | 4.29 | 0.89 |
| | HM3. greatly increases my motivation | 0.831 | 0.047 | 18.7 | | 4.01 | 1.05 |
| BI | BI1 I intend to use gamification in the coming months | 0.874 | 0.050 | 20.3 | 0.923 (0.922) | 3.48 | 1.17 |
| | BI2 I plan to use gamification in the near future | 0.930 | 0.047 | 22.6 | | 3.59 | 1.13 |
| | BI3 I expect to use gamification in the next period | 0.878 | 0.048 | 20.5 | | 3.47 | 1.12 |

**: only those indicators were kept in the model whose loadig was larger than the threshold of 0.6

Both McDonald's omega and Cronbach's alpha values suggested the highest reliability and factor consistency for BI and HM. In the case of PE, LV, PROS and CONS, the omega and alpha values were also excellent. All values were higher than the minimum of 0.7. Factor

loadings were also around or above the threshold of 0.7 and, therefore correlated well with the constructs. BI is described basically by B2, HM is represented the best with HM2, LV with LV2. The strongest indicator of PE was PE2 and EE2 in the case of EE. The main drawback of gamification was CON3 and the strongest advantage was PRO1.

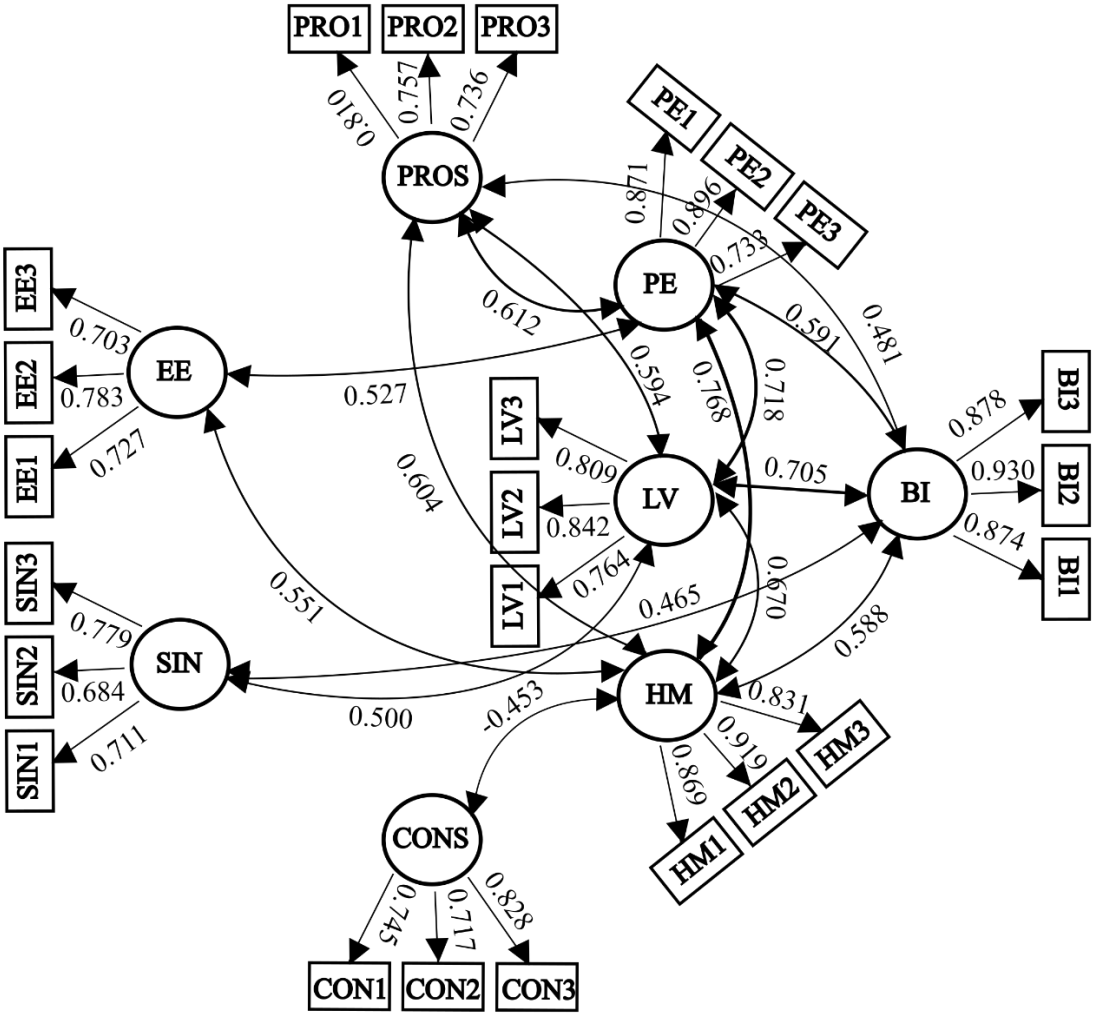



**Figure 1.** Graphical representation of the CFA model (loadings and construct correlations)

*Construct correlations were calculated by using Spearman's correlation (double headed arrows) Loadings were represented by single headed arrows only those correlations were depicted the absolute value of which was larger than 0.45.*
[Source: Authors' Calculation.]

Figure 1 presents the estimated CFA model with loadings and construct correlations. Spearman's correlation coefficient calculated construct correlations and all coefficients were significant at a 99.9% confidence level ($p<0.001$). Only those coefficients were depicted for

the sake of better understanding that were grater than 0.45. The largest correlation can be seen between PE and HM (r=0.768) and PE and LV (r=0.718). The best influential variable on BI was LV (r=0.708). It seemed that PE, LV, HM can be considered as mediator variables and EE and CONS did not affect BI directly. PROS mainly influenced PE, LV, HM but also had a direct relationship with BI (r=0.481). SIN also related directly through LV and indirectly to BI (r=0.465). Sample size (N) for CFA should satisfy the following 3 criteria (Myers et al., 2011): 1) $N \geq 200$; 2) $N/p \geq 10$, where p is the number of variables in the model; 3) $N/q \geq 5$, where q is the number of parameters in the model. The model contained 24 indicators, 8 latent variables and 28+24=52 model parameters (total number of arrows, 24 simple and (8*7)/2 double headed). Based on the above mentioned criteria, the sample size of 350 was satisfactory for the analysis. Figure 2 presents the clustering patterns of the indicators examined. The final clustering was done by K-means clustering using MacQueen's method, as this gave the highest Silhouette index compared to the other methods.

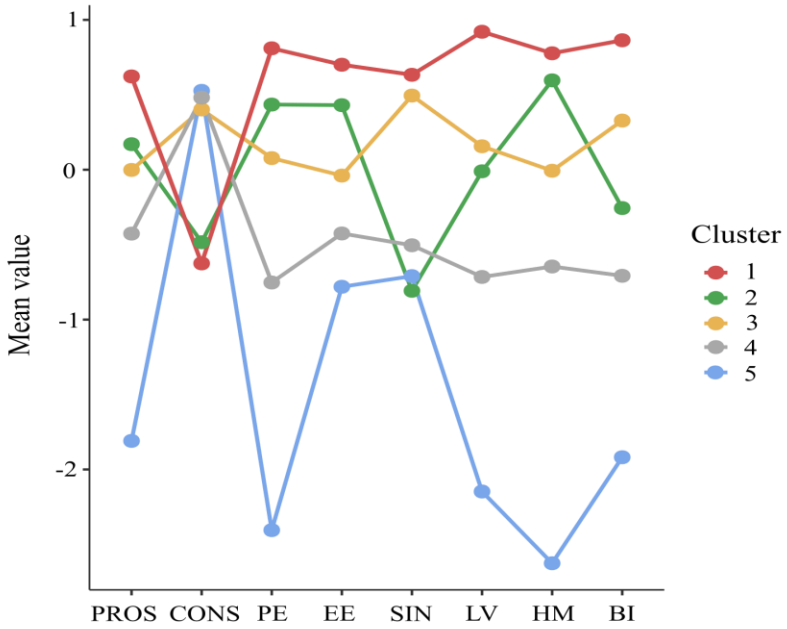
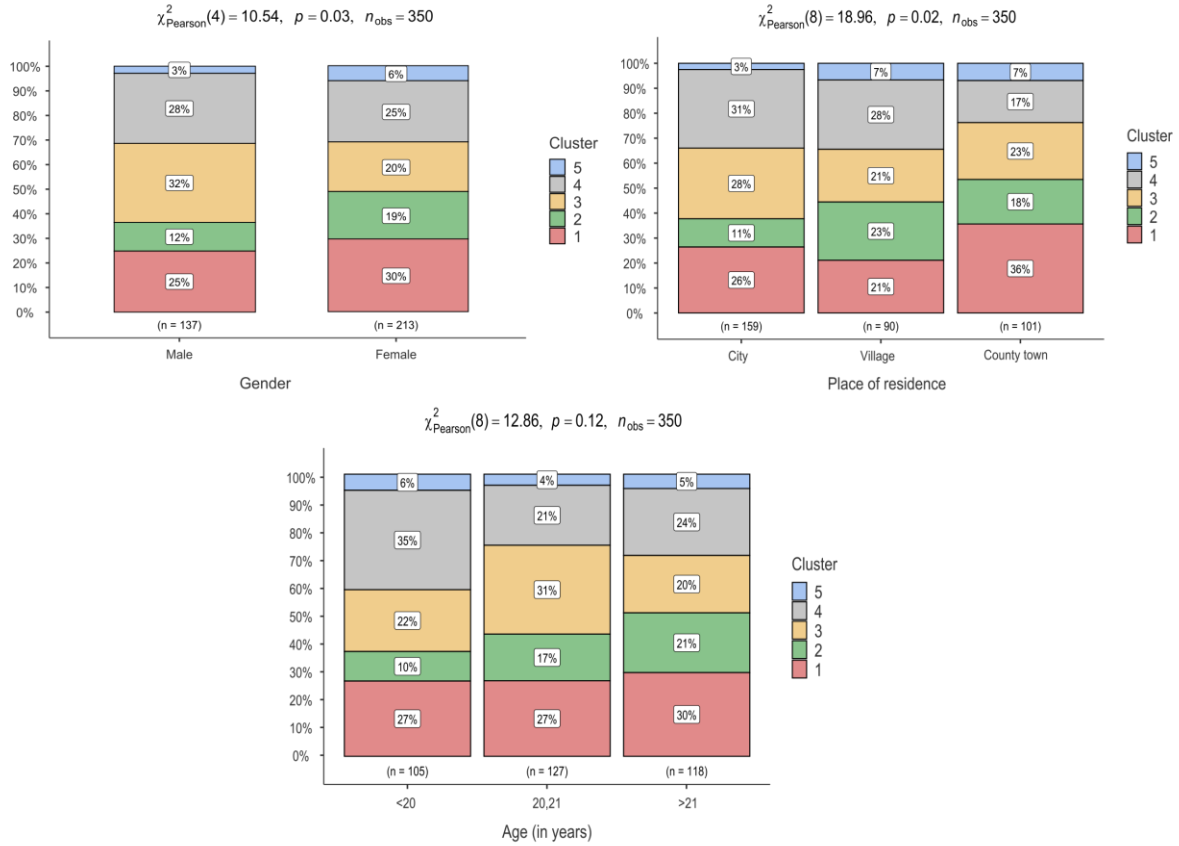



**Figure 2.** Indicator patterns (mean value differences) of the studied clusters

CFA constructs are standardized variables where a 0 value represents the average. Lower than the average values are negative numbers and positive values indicating above average values. There was a clear ordered pattern that can be detected by K-means cluster analysis (MacQueen's method). The optimal number of clusters was 5. Within the first two clusters (red and green) the respondents perceived more advantages towards gaming in education compared to the drawbacks. All other indicators were the highest in the first (red) cluster. In the second (green) cluster HM, EE, PE were also relatively high, but SIN was relatively lower compared to the 3rd (yellow) cluster. The 3rd cluster can be considered as the average group, while the worst two clusters are the 4th and 5th (gray and blue) clusters. The BI value as well as the perceived advantages of gamification in the education, HM, LV, PE were the lowest in the 5th (blue) cluster.

Figure 3 presents the results of the Chi-squared test and the distribution of cluster memberships between the different gender, age and place of residence groups. Differences are shown in a bar chart.




$\chi^2$ indicates the Chi-squared test statistic

**Figure 3.** Cluster distributions within Gender, Age and Place of residence categories

It can be stated that the proportion of red and green clusters (best two clusters with respect to gamification support) were relatively higher among Females (Chi-squared = 10.54; p=0.032). Place of residence also caused differences in the acceptance of gamification. The proportion of the first two clusters were the higher among those living in county towns (Chi-squared = 18.96; p=0.015). The results for gender and place of residence were statistically significant at the 5% level of significance ($p<0.05$). Altough older (over 22 years old) students were more supportive, as the ratio of the best two clusters was highest among them, no significant relationship with age could be found (Chi-squared = 12.86; p=0.117).

## DISCUSSION

The study aimed to explore the factors that may influence young students' attitudes towards technology adoption. Thus, the authors investigated certain UTAUT variables as well as arguments for (PRO) and against (CONS) gamification in a unified model. Although there have been several studies on the measurement of gamification and technology adoption and intention to use, the authors used the new approach presented previously to investigate complexity. The authors examined the attitudes of students in higher education and the factors that influence them from a new perspective. The results of the study may also help lecturers who have already introduced gamification in their teaching or are considering introducing it in their courses. Research to fill a gap in the literature has investigated the context of a version of the well-known UTAUT model supplemented with other constructs. The introduction of the new latent variables is an appropriate complement to existing academic work. Similar construct extensions have also been investigated by Hashim et al. (2018) & Altalhi (2021), where they highlight that openness and positive competition can promote intention to use in the presence of gamification.

The results show that PE and HM and PE and LV are the most correlated constructs. This result can be interpreted as indicating that, since young university students associate greater perceived usefulness with the method to be used (gamification), their hedonic motivation is related to their intrinsic motivation and reward system from using technology. This has been supported by several studies (Pappas, 2015; Lin et al., 2012; Mekler et al., 2017). BI, i.e. the intention to use, is most directly influenced by LV. Thus, the young people surveyed link their intention to use to their expected learning value. That is, the more learning value they associate with a technology, the more willing they are to use it. This is in line with the finding of other researchers that this depends on previous technology use and experience (Ofosu-Ampong et al., 2020). This finding is enhanced when the age factor is taken into account. In the following, the constructs PE, LV and HM act as a kind of proxy for BI. In contrast, EE and CONS do not directly affect the propensity to gamble.

Further analysis has shown that two clusters of young students in higher education are delineated, those who associate more benefits with gamification than negatives. They can be called gamification pioneers by the authors. The second cluster has relatively high values for HM, EE, PE but relatively low values for SIN. This group of students can be considered intrinsically motivated, but they do not consider themselves innovative. They can be considered as progressive. The third and fourth clusters were identified as the average group, while the fifth cluster had the lowest HM, LV, PE and BI values. This group was identified as gamification rejectors.

In terms of demographic variables, older students are more supportive of gamification in the classroom than their younger counterparts. This can be explained by the fact that they have been part of the higher education system for longer and are more open to technological innovation. However, this finding is not statistically significant; it merely highlights a trend. A similar finding was made by (Caserman et al., 2023; Larson, 2019, Kochoian, 2016; Aydin, 2018) in previous studies. In addition, the authors also found differences by place of residence. Those living in a city with county status (a large city) are significantly more open to gamification compared to those living in other areas. This finding is consistent with Koivisto

and Hamari's study in similar areas (Koivisto & Hamari, 2014;) that where we live may predispose our openness and acceptance.

## CONCLUSIONS

Overall, this study points out the conditions that promote the intention to use gamification in higher education. The authors have presented a multifaceted approach to gamification, the potential of the method in several areas of life, such as marketing, education, etc. The research has complemented some UTAUT variables with new contexts to investigate the complex factors that influence the intention to use gamification. The results indicated that there was a strong relationship between the constructs of learning value, hedonic motivation and expected performance, so intrinsic motivation and the possibility of easier learning through technology may be motivating these audiences. The paper also highlights the potential for demographic characteristics, revealing a significant effect between place of residence and intention to use, and with age as a variable, students in the older group are also more open to using gamification. The research found results consistent with those of several other studies, but with a new multi-criteria analysis that lecturers can take into account for their courses and university administrators when designing a course in the future.

## LIMITATIONS

The results of the study should be interpreted with caution. Firstly, the research is based on a survey of higher education students, which may limit how widely the results can be genralsed to other age groups or educational levels. Secondly, while statistical analyses revealed significant associations between gender, place of residence, and support for gamification, a non-significant trend was identified for age. Further research is needed to explore the extent to which age affects the acceptance of gamification in higher education, and to consider other moderator variables in the model. Thirdly, the study used a self-report questionnaire to collect data, which may have influenced respondents' answers due to bias or a concern for social desirability. Finally, as the study examined the adoption of gamification in a specific context, and different subjects or teaching methods may produce different results. Future research may wish to explore these contextual factors in more depth.

## THE THEORITICAL AND PRACTICAL IMPLICATIONS

The article highlights fundamental problems and opportunities in the higher education system. It stresses the need to look at today's young people at university from a new and innovative perspective. Fostering critical thinking and intrinsic motivation are all possibilities in a gamification-enhanced education. The study has identified and highlighted through research the factors that indirectly and directly influence the intention to use gamification. Students' sense of learning value and usefulness for a given subject or course is salient. The authors believe it can offer guidance to current and future instructors when designing the training and output requirements of a university course, as well as the semester of a course.

Setting clear objectives and motivational opportunities with appropriate reward systems can also be an excellent option for higher education. Gamification as a tool for increasing intrinsic motivation could also be included as a recommendation in the regulatory framework of educational institutions. Overall, the study may advance the adoption and implementation of gamification in higher education, both on the teaching and the institutional side, if decision-makers duly support it. This in turn, creates opportunities for self and institutional innovation, which will be a priority for future generations.

## ACKNOWLEDGMENT

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# ANALYZING CYBER-AGGRESSION TYPOLOGIES OF INDONESIAN ADOLESCENTS USING SECOND-ORDER CONFIRMATORY FACTOR ANALYSIS

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Abstract: *This study analyzed the most dominant dimension and significant indicator explaining the typology of cyber-aggression behavior among Indonesian adolescents using the second-order confirmation factor analysis (CFA) approach. The sample included 1354 senior high school adolescents, aged 18–21 years, who were recruited using the stratified random sampling method. Data were collected using a self-reporting approach. The results of the second-order CFA showed that the Controlled-Aversive latent variable, Controlled-Appetitive, Impulsive-Appetitive, and Impulsive-Aversive had loading factor indexes of 0.96, 0.85, 0.79, and 0.63, respectively. Thus, the Controlled-Aversive typology of cyber-aggression behavior was the most dominant among Indonesian adolescents. This proactive cyber-aggression behavior is manifested in the hostile behavior of planning proactively for revenge or responding in anger due to the provocation of social interaction stimuli in cyberspace.*

Keywords: *cyber-aggression, adolescents, confirmatory factor analysis, indonesian, high school student*


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## INTRODUCTION

In recent years, several studies on cyber-aggression (both as perpetrators and victims) among adolescents, particularly High School students, have been conducted. This is because adolescents in this age group serve as an ideal population in analyzing violent actions (and the victims of violence) perpetrated through the internet, which they extensively use daily. These patterns are supported by steep development of ICT (Roshchyk et al., 2022) with appropriate advantages and disadvantages, including cybercrimes (Kuzior et al., 2024; Yarovenko et al., 2023). According to Ortega-Ruiz and Gómez-Ortiz (2017), aggressive or deviant behaviors are often noticed during adolescence because it is associated with this specific developmental stage. Furthermore, individuals in this age group mostly spends their time accessing, interacting, and searching for information on social media (Tomczyk & Szotkowski, 2023). Studies on cyber-aggression revealed that many of these behaviors affect adolescents as both perpetrators and victims—a condition that has been associated with their behavior as intensive and massive technology users (Wachs et al., 2022). Furthermore, this developmental stage has often been associated with aggressive behavior, such as hate speech (Bedrosova et al., 2022). Cyber-aggression exists due to different values and perspectives among individuals and groups in cyberspace, which can lead to psychological instability (Mardianto et al., 2020, 2021, 2023).

In accordance with the cyber-aggression typology developed by Runions et al. (2016), several studies on cyber-attacks by adolescents, specifically in Indonesia, have been conducted. However, to date, no specific explanations of the frequencies of certain types have been presented. Therefore, this current study was conducted with the goal of describing and explaining the patterns and characteristics of cyber-aggression committed by adolescents in Indonesia. Subsequently, policymakers and educational institutions can apply the results of this study to provide more targeted interventions in controlling and preventing cyber-aggressive behaviors among Indonesian youth (Chamizo-Nieto et al., 2020).

Runions et al. (2016) employed the cyber-aggression concept that was developed based on the relationship between personality disorder and violence. On the basis of individual motives and self-control, Howard (2015) distinguished violent behaviors into four typological sections ($2 \times 2$), consisting of intersection (impulsive vs. control) and influence (positive vs. negative). These four different types of violence are characterized by the motive of obtaining pleasure/excitement and desire/greed, which are related to positive influence and revenge, respectively. Furthermore, Howard (2015) proposed a theory called the quadripartite model of aggression (QMA) to understand aggression from two different psychological perspectives. The QMA argues that the two psychological motivations that contribute to an individual's aggression include regulatory control (RC; impulsive vs. controlled) and motivational goal (MG; appetitive vs. aversive). In particular, RC refers to how individuals perceive aggression based on their cognitive function. As part of RC, "impulsivity" is defined as an unconscious act of aggression in response to a specific emotional object, while a controlled attack refers to a deliberate action. While RC focuses on intentional actions, MG concentrates on the emotional condition representing aggression.

Moreover, aggression can be classified into two subtypes: hot-blooded/reactive and cold-blooded/proactive. These two varieties of aggression can be extremely harmful to victims depending on their motivation. The "hot-blooded type" refers to a spontaneous violent response to provocation, while the "cold-blooded type" is associated with antisocial conduct and

involves the use of purposeful or malicious acts to accomplish a goal. In accordance with frustration–anger theory, reactive aggression can be described as "hot-blooded" impulsive violence characterized by negative emotional valences, such as rage, embarrassment, humiliation, and shame (Kruglanski et al., 2023).

On the basis of the abovementioned classification and characteristics of aggressive behaviors, Runions et al. (2016) divided cyber-aggression into four typologies to better explain the reasons people attack in cyberspace. The first typology is "Impulsive-Aversive," which refers to a reactive and spontaneous cyber-aggressive response to a perceived provocation. In this scenario, the individual feels embarrassed or provoked by heated emotions (with an indication of cyber behavior in the form of online words/behaviors) to attack other individuals considered as "enemies." This type of cyber-aggressive behavior is often manifested in online expressions of words/behaviors that are full of hostility, thereby creating a heated atmosphere. This behavior also involves the use of harsh words to attack others as a form of spontaneous reaction to a perceived provocation that makes individuals feel embarrassed or provoked (Rivas-Rivero & Bonilla-Algovia, 2022).

The second type is "Controlled-Aversive," which comes in the form of proactive cyber-aggressive behavior. In this typology, online statements/behaviors manifest as hostile actions that are planned proactively for revenge or to threaten someone as a result of anger (Rivas-Rivero & Bonilla-Algovia, 2022).

Furthermore, the third type is "Controlled-Appetitive," which is a form of proactive cyber-aggression aimed to insult, ridicule, and criticize others. This typology constitutes planned enjoyment to do something to achieve a positive impression, such as feeling happy or satisfied, as a psychological reward. Online behaviors that aim to embarrass, intimidate, and attack someone as a form of planned fun to gain social attention belong to this category (Rivas-Rivero & Bonilla-Algovia, 2022).

The fourth is "Impulsive-Appetitive," which is a reactive cyber-aggressive behavior that includes embarrassing online statements. This type involves a spontaneous attack of individuals based on the mere impulse to have fun (Rivas-Rivero & Bonilla-Algovia, 2022).

## METHODS

This study employed a quantitative approach using second-order Confirmatory Factor Analysis (CFA) to validate the typology of cyber-aggression in Indonesian adolescents. The goal was to test whether the theoretical four-factor model fits the empirical data collected from a representative adolescent population.

### Data Collection Procedures

In this study, data were collected using the web-based self-report personality scale technique. The objective of this self-report approach is to ascertain the psychometric properties of a single measure, such as the frequency of item validation, scale reliability, score distribution, and factor structure. The total sample comprised 1354 adolescents, aged 18–21 years, all studying high school in Indonesia. The participants consisted of 972 females (71.8%) and 328 males (28.2%). The domicile consists of 12 metropolises (6%), 98 cities (49%), and 91 towns (45%).

The technique used to recruit the participants was purposive sampling—a method of selecting subjects based on the criteria established for the study.

### Measurement

The cyber-aggression scale consisted of 50 items divided into favorable and unfavorable patterns and were scored using a Likert-type scale with response choices ranging from 1 to 4. According to Souza et al. (2017), instrument testing is required before performing data analysis using validity and reliability tests. In this study, the measurement was conducted using the developed adolescents' Cyber-Aggression Scale.

### Data Analysis

This research aimed to analyze the types and characteristics of cyber-aggressive behavior of Indonesian adolescents. second-order confirmatory factor analyses (CFA) were conducted. This measurement model in structural equation model (SEM) consists of two levels, which show the relationship between latent variables at the first level as indicators of a second level latent variable (Limkhunthammo et al., 2023). In this study, second-order CFA analysis was used to obtain the dominant indicators in compiling the latent variable, namely, Indonesian adolescent cyber-aggression.

### Reliability

The statistical summary for a person's reliability score having 0.84 CASIA shows that each instrument has sufficient quality answers given by the person. Meanwhile, the reliability value on the CASIA instrument = 0.99 means that the item quality is very good for the given measurement conditions. The Cronbach's alpha value (KR-20) on the CASIA instrument = 0.94 indicated that the interaction between person and item is sufficient (Kyriazos & Stalikas, 2018).

### Construct Validity

Construct validity describes how well the measurement follows theoretical expectations (Boone et al., 2014). The residual principal component analysis (PCA) is typically used to determine the extent to which the diversity of instruments can be measured. The two parameters considered in the PCA analysis are the total raw variance in observation (at least 20%), and the total raw unexplained variance (minimum 15%) (Linacre, 2011; Sumintono & Widhiarso, 2015). Further information is presented in Table 3.

## RESULTS

CFA aims to test whether the data match the hypothesized model. The CFA is a model that connects latent variables with their indicators (Furr, 2014). Based on the analytical performance, CFA focuses on two questions: (1) Are the indicators conceptualized in a unidimensional, precise, and consistent manner? And (2) Which dominant indicator forms the study construct? Apart from this, the CFA is divided into two: first-order and second-order CFA. The difference between these two types is that the latent variables in second-order CFA

are not directly measured through assessment indicators but through other latent variables (Hair et al., 2019).

Specifically, the second-order CFA analysis was used in the current study to obtain the dominant indicator when compiling the latent variable of Indonesian adolescents' cyber-aggression. This model was analyzed with several trials and combinations of all possible indicators. Therefore, optimum results, which were considered valid and reliable, were obtained based on the indicators satisfying the suitability criteria. In accordance with the CFA objective of determining a fit latent variable, a measurement model was evaluated using the goodness-of-fit criterion. The second-order CFA modeling results on Indonesian adolescents' cyber-aggression are shown in Figure 1.

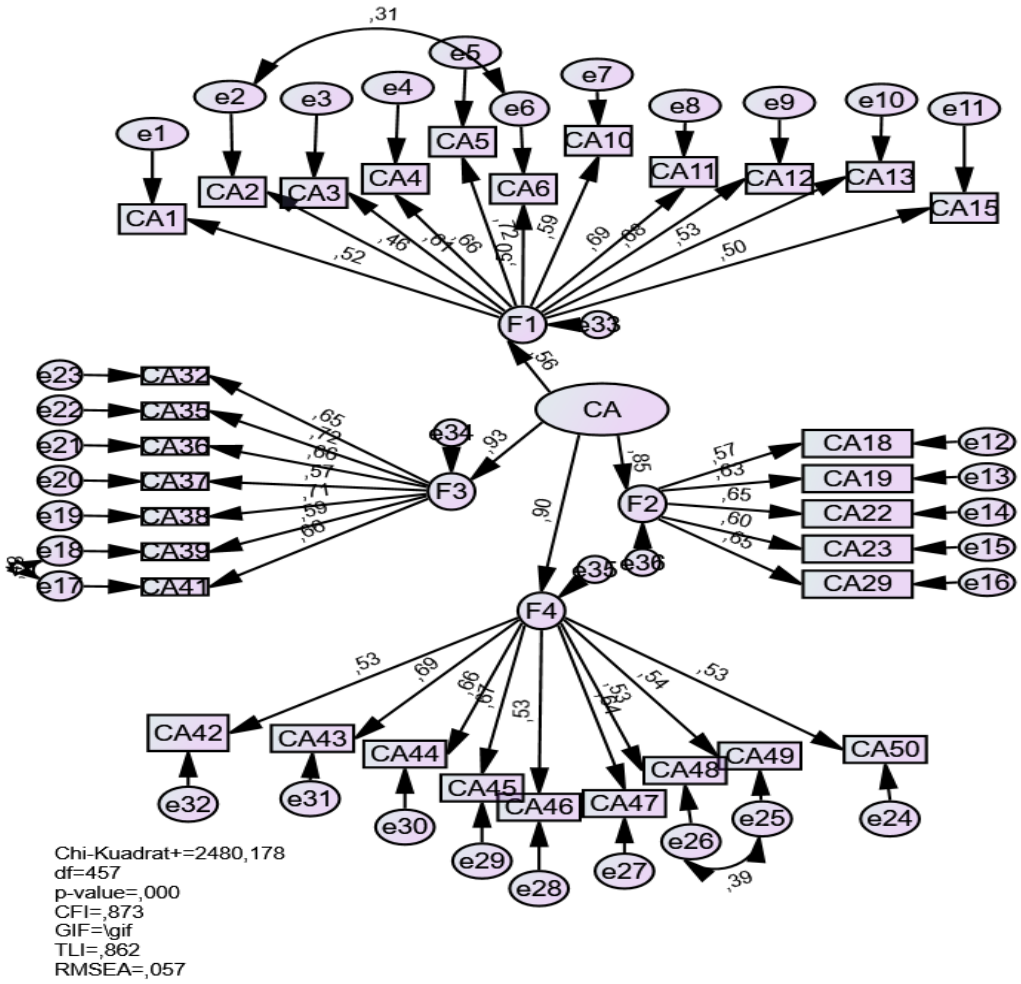


**Figure 1.** CFA test results of the cyber-aggression scale before the goodness-of-fit-model

The test results in Figure 1 reveals that the model is infeasible and hypothetically unacceptable because it does not meet several standards of conformity index or absolute fit size, as well as the rule of thumb in the SEM analysis.

**Table 1.** Model suitability test results

| Index | *Goodness-of-Fit* | Criteria | Description |
|---|---|---|---|
| Chi-Square | 2480, 178 (p-value = 0.000) | p-value > alpha 5% | Not feasible |
| CMIN/DF | 5.427 | ≤2.00 | Not feasible |
| CFI | 0.873 | ≥0.92 | Not feasible |
| TLI | 0.862 | ≥0.92 | Not feasible |
| RMSEA | 0.057 | ≤0.08 | Feasible |
| GFI | 0.888 | ≥0.90 | Not feasible |
| AGFI | 0.870 | ≥0.90 | Not feasible |

To obtain perfect goodness-of-fit results, the AMOS 26 application provides output properties for model modification analysis by displaying the symmetrical relationship between 1) one variable and another, 2) variables and errors, and between 3) one error variable and another. It is important to note that this aforementioned process is in line with the modification index guideline (Hair et al., 2014; Haryono, 2017).

Furthermore, the Cyber-Aggression Scale consists of four factors related to the cyber-aggressive behavior types: 1) Impulsive-Aversive (Im_Av), 2) Controlled-Aversive (Co_Av), 3) Controlled-Appetitive (Co_Ap), and 4) Impulsive-Appetitive (Im_Ap). The number of items utilized based on the reliability and discriminating power test result was 50. After performing the CFA, there were still 19 feasible and reliable items for measuring the adolescents' cyber-aggression, as shown in the following chart.

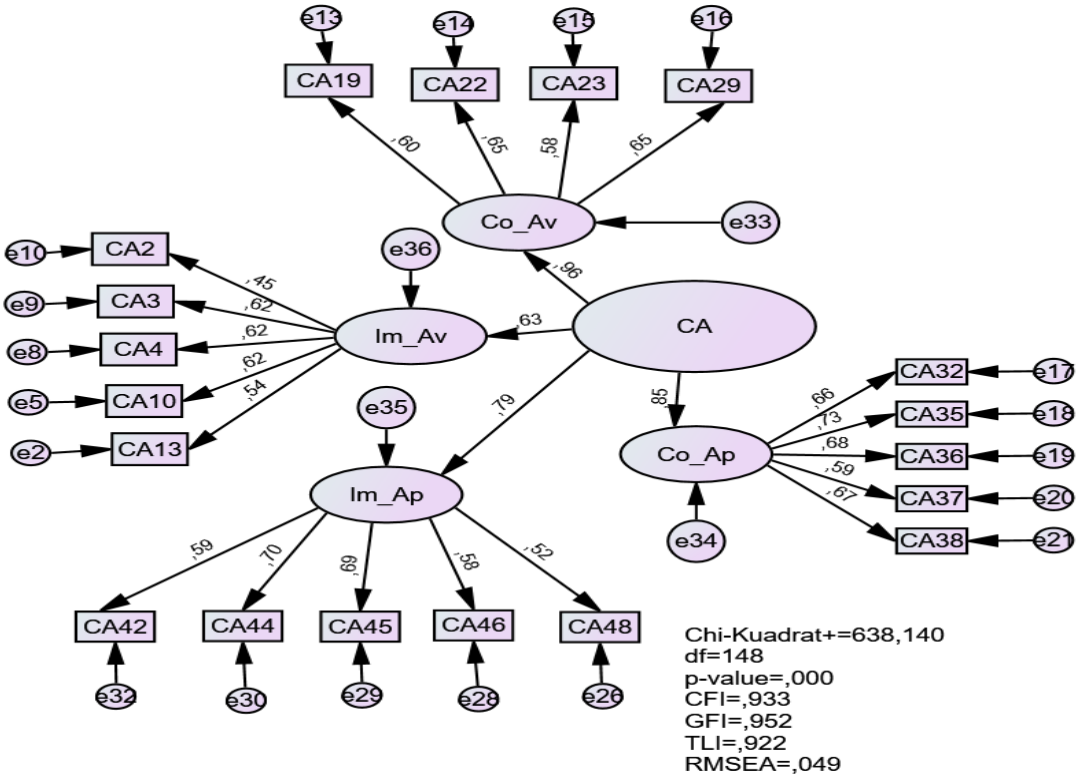


**Figure 2.** CFA test results of the cyber-aggression scale after the goodness-of-fit model

The items with a loading factor above 0.45 and had no cross-loading with other items were selected based on the CFA shown in Figure 3. The goodness-of-fit parameters, including AGFI, GFI, TLI, CFI, and RMSEA, showed that all indicators met the fit criteria, except for the chi-square indicator. Therefore, it can be concluded that the cyber-aggression construct measurement model corresponded to the empirical conditions. The number of initial items planned was 50, of which 19 met the load factor criteria above 0.45, representing four cyber-aggression factors. In this model, the Impulsive-Aversive factor (Im_Av) is represented by items CA2, CA3, CA4, CA10, and CA13; Controlled-Aversive (Co_Av) is indicated by CA19, CA22, and CA29; Controlled-Aversive (Co_Ap) is denoted by CA32, CA35, CA36, CA, 37, and CA 38; while the Impulsive-Appetitive (Im_Ap) is characterized by CA42, CA44, CA45, CA46, and CA48.

**Table 2.** Standardized factor loadings based on the CFA of CASIA (N=1354)

| No | Item | (Im_Av) | (Co_Av) | (Co_Ap) | (Im_Ap) |
|---|---|---|---|---|---|
| CA2 | It's easy to get angry when I get posts that insult my tribe and culture, and I strike back. | 0,45 | | | |
| CA3 | When someone sends me a hurtful message, I reply right away. | 0,62 | | | |
| CA4 | Quickly reply loudly to someone's post that offended me. | 0,62 | | | |
| CA10 | Immediately react to an attack when I see an online order that makes me angry. | 0,62 | | | |
| CA13 | When someone posts something that hurts me, I immediately reply to a post that attacks them. | 0,54 | | | |
| CA19 | Making posts that embarrass someone who has been making fun of me on the internet. | | 0,60 | | |
| CA22 | Expressing anger by writing insults to a certain person or group who has hurt my feelings or humiliated me. | | 0,65 | | |
| CA23 | Sending insults that heat up people or groups that I consider enemies on social media. | | 0,58 | | |
| CA29 | Insinuating with the ridicule of people who are pretentious on social media. | | 0,65 | | |
| CA32 | Making posts that embarrass someone who isn't liked so that others won't like them either. | | | 0,66 | |
| CA35 | Share posts to embarrass people you don't like. | | | 0,73 | |
| CA36 | Using fake accounts on the internet to ruin someone's relationship. | | | 0,68 | |
| CA37 | Make a post that satirizes someone so that he/she looks like a fool. | | | 0,59 | |
| CA38 | Share posts that poke fun at certain ethnicities for fun with friends. | | | 0,67 | |
| CA42 | Made a post as a joke, but other people get offended. | | | | 0,59 |
| CA44 | Joking on social media by not caring if someone's feelings are hurt. | | | | 0,70 |

| No | Item | (Im_Av) | (Co_Av) | (Co_Ap) | (Im_Ap) |
|---|---|---|---|---|---|
| CA45 | Sending posts that annoy people online because I think it's funny. | | | | 0,69 |
| CA46 | Joking on social media is so much fun that I don't worry about whether someone might be bothered by what I say. | | | | 0,58 |
| CA48 | Writing harassing words on social media groups just for fun. | | | | 0,52 |

Several suitable indicators were used to determine the model fit size, including 1) the chi-square and df values; 2) the absolute fit index, such as GFI, RMSEA, or SRMR; 3) the incremental fit index, namely, CFI or TLI; 4) the goodness-of-fit index (GFI), consisting of GFI, CFI, or TL; and 5) the bad match index, which involves RMSEA or SRMR. For the absolute fit index indicator, namely, the GFI, the range of values is 0–1. When the value is high, the match tends to be better.

The results of testing the second model, shown in Figure 2, shows that the standard criteria for conformity index or absolute fit size and rule of thumb are not significantly different from the first model in Figure 1. The details can be seen in Table 3.

**Table 3.** Model fit test results after the goodness-of-fit model

| Index | *Goodness-of-Fit* | Criteria | Description |
|---|---|---|---|
| Chi-Square | 638,140 (p-value = 0.000) | p-value > alpha 5% | Not feasible |
| CMIN/DF | 4,312 | ≤ 2.00 | Not feasible |
| CFI | 0.933 | ≥ 0.92 | Feasible |
| TLI | 0.922 | ≥ 0.92 | Feasible |
| RMSEA | 0.049 | ≤ 0.08 | Feasible |
| GFI | 0.952 | ≥ 0.90 | Feasible |
| AGFI | 0.938 | ≥ 0.90 | Feasible |

## DISCUSSION

The population of this study included high school students in Indonesia. Based on the results of the descriptive analysis, the majority of respondents came from Java and Sumatra, of whom 31.2% were of Minang ethnicity, 49.0% of Javanese ethnicity, and the rest consisting of members of other ethnic groups in Indonesia. Even though there was a representation of student respondents from outside the islands of Java and Sumatra in this study, the number of respondents who came from outside the regions of the two islands remained small, especially for the eastern part of Indonesia. As such, the generalization power of this study may be somewhat limited, but the good news is that theoretically the characteristics of adolescent development and the characteristics of communication behaviors in networks or cyberspaces do not have a very significant differential range (Nilan et al., 2015).

The abovementioned result simultaneously answered the main hypothesis of this study on the typology of cyber-aggression among Indonesian adolescents. The findings indicate that the model developed and tested under empirical conditions in the field is consistent with the theoretical elements of the typology and characteristics of individual cyber-aggression

compiled within the framework. This suggests that the main hypothesis in this study is accepted as the model can explain the factors that shape the typology of cyber-aggression among Indonesian adolescents. The structural equation analysis also proved that the model met the goodness-of-fit according to the following index criteria: CMIN/DF, GFI, AGFI, TLI, CFI, and RMSEA.

The model analysis showed that the latent variable for the Impulsive-Aversive obtained a loading factor index of 0.63. Furthermore, the Impulsive-Appetitive, Controlled-Aversive, and Controlled-Appetitive are 0.7, 0.96, and 0.85, respectively. It was discovered that the dominant type of cyber-aggressive behavior among adolescents is the Controlled-Aversive. This behavior is a proactive cyber-aggression in the form of hostile behavior, planned proactively for revenge or as a response to anger due to the provocation of social interaction stimuli in virtual space.

These results support the findings of previous studies, which indicate that aggressive behaviors, such as hate speech, occur on social media because individuals feel unfairly treated, morally and materially offended, and abused or bullied (Yusuf et al., 2021). Consequently, such scenarios drive individuals to express extreme hate and anger toward anyone considered an enemy through speeches and posts on social media (Jaishankar, 2008; Titley et al., 2012; Burnap & Williams, 2016; Jablonska & Polkowski, 2018).

Other factors that describe hateful behaviors according to Levin and McDevitt (Walters et al., 2016) are the different typologies of hate crimes, such as seeking sensation, self-defense, and revenge. These factors are part of the mission of certain ideological groups to terrorize other individuals or groups. As explained by McDevitt et al. (Walters et al., 2016), 66% of hate speech actors seek sensation, and perpetrators usually act in groups with one or two leaders. Levin and McDevitt also stated that 25% of perpetrators are classified as “defensive” and are mostly motivated by a perceived threat to their territory (Walters et al., 2016).

The presence or existence of outside groups is perceived as a threat by individuals, giving birth to negative emotions that, in turn, lead to hate speech and other cyber-aggressive behaviors. Other studies also explained the effects of intergroup threats on human thoughts, brains, and behaviors and showed that intergroup threats also have an impact on online visual processing, from the initial coding of the stimulus to further attention modulation. This means that intergroup threats are one of the catalysts that transform individuals from passive disregard for outside groups into active hostility (Maxwell, 2016; Chang et al., 2016).

Neuroscience theory explains that aggressiveness involves interactions between two brain circuits known as biobehavioral systems: negative valence systems (NVS) and cognitive systems (CS). According to this theory, the response to threats and information processing systems in such a way gives rise to aggression, especially in emotional states. This is because brain circuits that are activated by acute threats (in NVS) favor emotionally aggressive behaviors, which means that brain circuits that are often triggered by feelings of threat disrupt high-level cognitive processes and can trigger aggression (Verona & Bozzay, 2017). Furthermore, in the theory of threat or integrated threat, the threat perception is grouped into three types, namely, personal threat, intergroup threat, and no threat. A personal threat is a threat directed at oneself, such as individuals who receive negative criticism at school or work so they feel that their personal identities are being attacked, labeled, and/or categorized as being threatened minus the self-resources they possess (Redmond & Alderton, 2016).

## CONCLUSION

The phenomenon of cyber-aggression in Indonesia is currently a serious and worrying problem, particularly when it involves adolescents. This is because cyber-aggression can have negative legal and psychological consequences on those involved. The findings of this study can be used as a basis for developing targeted interventions to effectively prevent and reduce such behaviors.

The results of the second-order CFA showed that the Controlled-Aversive latent variable of cyber-aggression has a loading factor index of 0.96. In addition, the Controlled-Appetitive, Impulsive-Appetitive, and Impulsive-Aversive have indexes 0.85, 0.75, and 0.63, respectively. Thus, it can be concluded that the dominant typology of cyber-aggressive behavior among Indonesian adolescents is Controlled-Aversive. As defined earlier, this is a proactive cyber-aggression in the form of proactively planned hostile behaviors for revenge or as a response to anger caused by provoked stimulation of social interactions in cyberspace.

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# Appendix

## Cyber Aggression Scale for the Indonesian Adolescent (CASIA)

| No. | Statement of scale | 1. = Never<br>2. =Sometimes<br>3. =Often<br>4. =Always | | | |
|---|---|---|---|---|---|
| 1 | When someone attacks me on social media, I immediately respond with the same behavior | 1 | 2 | 3 | 4 |
| 2 | It's easy to get angry when I get posts that insult my tribe and culture and I strike back | 1 | 2 | 3 | 4 |
| 3 | When someone sends me a hurtful message I reply right away | 1 | 2 | 3 | 4 |
| 4 | Quickly reply loudly to someone's post that offended me. | 1 | 2 | 3 | 4 |
| 5 | Easy to get emotional and reply right away when someone makes fun of me on the internet | 1 | 2 | 3 | 4 |
| 6 | Hit back hard when someone says something bad about my religion on social media | 1 | 2 | 3 | 4 |
| 7 | Commenting on someone's link/status scathingly causes the emotional atmosphere between us to heat up | 1 | 2 | 3 | 4 |
| 8 | Engage in debates that lead to disagreements with others on social media | 1 | 2 | 3 | 4 |
| 9 | Commenting on someone's post cynically causes the emotional atmosphere to heat up | 1 | 2 | 3 | 4 |
| 10 | Immediately react to attack when I see an online order that makes me angry | 1 | 2 | 3 | 4 |
| 11 | Immediately reply with even louder insults when someone bullies and attacks me on social media | 1 | 2 | 3 | 4 |
| 12 | When someone posts something that hurts me, I immediately post a reply that attacks them | 1 | 2 | 3 | 4 |
| 13 | When someone posts something that hurts me, I immediately reply to a post that attacks them | 1 | 2 | 3 | 4 |
| 14 | Sending posts that contain insults to someone on social media because they don't like their behavior | 1 | 2 | 3 | 4 |
| 15 | Respond very quickly to messages or posts that are rude to me | 1 | 2 | 3 | 4 |
| 16 | Writing swear words to unscrupulous officials on social media | 1 | 2 | 3 | 4 |
| 17 | Sending direct threats against someone who has hurt and demeaned me. | 1 | 2 | 3 | 4 |
| 18 | Writing posts to avenge the hurt on people who have been hostile to me | 1 | 2 | 3 | 4 |
| 19 | Making posts that embarrass someone who has been making fun of me on the internet | 1 | 2 | 3 | 4 |
| 20 | Using social media accounts to plot revenge when someone upsets me | 1 | 2 | 3 | 4 |
| 21 | Write comments on social media in abusive language towards other people who don't like | 1 | 2 | 3 | 4 |
| 22 | Expressing anger by writing insults to a certain person or group who has hurt my feelings or humiliated me | 1 | 2 | 3 | 4 |
| 23 | Sending insults that heat up people or groups that I consider enemies on social media | 1 | 2 | 3 | 4 |
| 24 | Various provocative images for disturbing purposes | 1 | 2 | 3 | 4 |
| 25 | I send threatening messages to enemies or people who are hostile to me via social media | 1 | 2 | 3 | 4 |
| 26 | Creating fake accounts on social media to threaten or scare someone who has hurt me | 1 | 2 | 3 | 4 |
| 27 | Thinking that it is very easy to threaten someone you don't like through social media nowadays because you can directly chat with that person | 1 | 2 | 3 | 4 |
| 28 | Share posts about celebrities you don't like so others don't like them too | 1 | 2 | 3 | 4 |
| 29 | Insinuating with the ridicule of people who are pretentious on social media | 1 | 2 | 3 | 4 |
| 30 | Sharing rumors about other people's religions on social media | 1 | 2 | 3 | 4 |
| 31 | Sharing posts that make fun of other people's religion on social media in return for insulting my religion | 1 | 2 | 3 | 4 |
| 32 | Making posts that embarrass someone who isn't liked so that others don't like them either | 1 | 2 | 3 | 4 |
| 33 | Making embarrassing posts about someone you don't like so that other people don't like it too | 1 | 2 | 3 | 4 |
| 34 | Share funny posts that make fun of someone so others laugh | 1 | 2 | 3 | 4 |
| 35 | Share posts to embarrass people you don't like | 1 | 2 | 3 | 4 |
| 36 | Using fake accounts on the internet to ruin someone's relationship | 1 | 2 | 3 | 4 |
| 37 | Make a post that satirizes someone so that it looks like a fool | 1 | 2 | 3 | 4 |
| 38 | Share posts that poke fun at certain ethnicities for fun with friends | 1 | 2 | 3 | 4 |
| 39 | Sharing funny picture posts that make fun of certain political figures as a joke | 1 | 2 | 3 | 4 |
| 40 | Making posts that satirize or embarrass someone to make them realize and change from their wrong behavior | 1 | 2 | 3 | 4 |
| 41 | Sharing posts that make fun of officials/officials on social media for jokes | 1 | 2 | 3 | 4 |
| 42 | Made a post as a joke but other people get offended | 1 | 2 | 3 | 4 |

| No. | Statement of scale | 1. = Never<br>2. =Sometimes<br>3. =Often<br>4. =Always | | | |
|---|---|---|---|---|---|
| 43 | Make fun of unknown people on social media without thinking whether they will see it or not | 1 | 2 | 3 | 4 |
| 44 | Joking on social media, by not caring if someone's feelings are hurt | 1 | 2 | 3 | 4 |
| 45 | Sending posts that annoy people online because I think it's funny | 1 | 2 | 3 | 4 |
| 46 | Joking on social media is so much fun that I don't worry about whether someone might be bothered by what I say | 1 | 2 | 3 | 4 |
| 47 | Sharing satire writings that make fun of certain tribes and ethnicities on social media for jokes | 1 | 2 | 3 | 4 |
| 48 | Writing harassing words on social media groups just for fun | 1 | 2 | 3 | 4 |
| 49 | Insulting friends in social media groups for jokes | 1 | 2 | 3 | 4 |
| 50 | Share memes that insult political figures in social media groups to keep other members of the group entertained | 1 | 2 | 3 | 4 |

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# INFORMATION AND COMMUNICATION TECHNOLOGIES TO PROMOTE HEALTHY AGEING: A RURAL COMMUNITY INTERVENTION DURING COVID-19 PANDEMIC

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Abstract: *This pilot study evaluates a community intervention using information and communication technologies (ICT) to enhance cognitive activity and subjective well-being in older adults. Conducted during the final phase of the COVID-19 pandemic with a pre-test and post-test design, the study involved Group 1 (n = 11) and Group 2 (n = 12), who participated in a learning program using ICT to stimulate autobiographical memory and social interaction. In addition, Group 1 received training on stress coping strategies based on mindfulness-based cognitive therapy, while Group 2 reflected on the digital inclusion of older people. Following the intervention, Group 1 demonstrated significant improvements in performance on the Trail-Making-A Time and Stroop Words tasks, while Group 2 showed improvement on the Trail-Making-B Time task; all of these measures are related to executive function. Depression decreased in both groups. Most indicators of positive well-being remained stable after the intervention, with some showing a tendency to improve. These findings suggest that this community intervention is suitable for older adults and contributes to improved cognitive abilities and subjective well-being. Complementing the quantitative evaluation, a subsequent qualitative study was conducted with 20 older adults who had participated in the learning program, utilizing a participatory approach to gain deeper insights into their experiences and needs. The results indicated that the most valued aspects of the intervention were the in-person opportunities to learn how to use technology in daily life and to share reminiscences. Participants also emphasized the importance of practice opportunities and the empathetic support provided by facilitators throughout the activities.*

Keywords: *older adults, healthy ageing, information and communication technologies (ICT), cognitive abilities, subjective well-being, community intervention.*


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## INTRODUCTION

*Healthy ageing* is defined by the World Health Organization (WHO, 2015) as the "process of developing and maintaining the functional ability that enables well-being in older age" (p. 28). Functional ability consists of intrinsic capacity, a composite of an individual's physical and mental capacities, and environments, which comprise all the external factors that shape the context of an individual's life. From this perspective, environments can promote healthy ageing by reducing risks, encouraging healthy behaviours, removing barriers, and providing targeted services. Several models highlight that maintaining cognitive abilities (such as processing speed, working memory, executive functions, attention, and inhibition) and high levels of well-being (including happiness, satisfaction, and fulfilment) are key determinants of healthy ageing. Although normative ageing (i.e., non-pathological ageing) may involve a decline in cognitive abilities, such decline can be delayed or even reversed through healthy lifestyles, supportive environments, and appropriate interventions (Baltes & Baltes, 1990; Carstensen, 2006; Kahana, 1996; WHO, 2015).

Another relevant aspect of healthy ageing is "ageing in place," which emphasizes the right of older people to live and be included in their community, since it is linked to security, connection, familiarity, identity, and autonomy (WHO, 2015). During the COVID-19 pandemic, most older adults were required to remain at home to mitigate related health risks. This context placed into question the efficacy of the ageing-in-place strategy (Pinazo-Hernandis et al., 2022; Streimikiene, 2025). For example, evidence revealed that the pandemic particularly disadvantaged older adults without access to, or skills in using, ICT, especially those with technophobia (Nimrod, 2021), thereby increasing social isolation in this age group (Roe et al., 2021; Seifert, 2021).

Supporting cognitive capacity, subjective well-being, and social participation in the community throughout the lifespan - and particularly in old age - therefore shows promise for enhancing healthy ageing. Previous research has demonstrated that information and communication technologies (ICT), including digital applications and devices, have the potential to support health care and cognitive training (Halmdienst et al., 2019; Morrison & McCutheon, 2019; Ryd et al., 2018), leisure and social relationships (Halmdienst et al., 2019; Spasova, 2023; Vulpe & Crăciun, 2020), social networks (Bilan et al., 2023; Chen & Schulz, 2016; Hasan & Linger, 2016; Righi et al., 2017; Vulpe & Crăciun, 2020), subjective well-being (Diaz-Lopez et al., 2016; Hur, 2016; Ryd et al., 2018; Saari et al., 2024), and learning opportunities (Díaz-López et al., 2016; Martinez et al., 2025; Mitzner et al., 2019; Morrison & McCutheon, 2019) for older adults.

It has been observed that using ICT for cognitive stimulation (general practices that help maintain and improve cognitive performance, such as staying active, engaging in learning processes, and participating in social activities) and cognitive training (exercises targeting specific cognitive abilities such as attention, memory, and processing speed) positively impacts older adults' cognitive performance. Some studies have reported a small but statistically significant effect size on overall cognitive functioning (Contreras-Somoza et al., 2021; Rosell, 2018) and decreased depressive symptomatology (Rosell, 2018) among older adults who engaged in computer-based cognitive stimulation activities. The use of virtual reality in cognitive interventions has been well accepted by older adults, with evidence of increased positive affect and reduced negative affect (Chan et al., 2020). Technological

interventions also foster cognitive engagement by involving participants in highly motivational and cognitively demanding activities, such as learning to use new digital technologies (Djabelkhir et al., 2017). Both types of interventions, cognitive stimulation and cognitive engagement, contribute to improvements in various aspects of cognitive performance and psychosocial functioning (Djabelkhir et al., 2017).

Despite these benefits, a substantial proportion of older adults do not use ICT in their daily lives. For instance, while Internet use in the United States is nearly universal among younger and middle-aged populations (90%), only 73% of people over 65 years report using it (Pew Research Center, 2019). In Costa Rica, in 2020, 74.71% of people aged 60 years and older had Internet access at home; however, only 11.84% had a desktop computer, 34.03% owned a laptop, 10.56% had a tablet, and 92.27% possessed a mobile phone (INEC, 2020). Among older adults, the digital divide has been the largest and most persistent between 2010 and 2017 (PROSIC, 2018).

For this population, the digital divide is associated with six basic factors: income, education, gender, age, geographic location, and disability (PROSIC, 2010). Research further suggests that older adults' difficulties in learning and using ICT are linked to limited prior experience, negative emotions associated with the learning process - particularly fear and shame - and insufficient individual support from family, friends, and instructors (Castro-Rojas, 2021; Castro-Rojas et al., 2016, 2018; Coto et al., 2017).

Involving older adults in the design and evaluation of interventions targeting ICT learning and use could be a strategy to promote more sensitive and contextualized interventions (Davis et al., 2021; Sumner et al., 2021). In a participatory approach the basic principle is that involving potential end-users during the process leads to outcomes better aligned with their needs, capabilities, and characteristics (Pelta Resano, 2022). In recent years, this approach with older adults has increased, highlighting opportunities and challenges in technological innovation (Duque et al., 2019).

To help overcome barriers related to geographic location and negative emotions associated with the learning process, the present study focuses on improving cognitive abilities and subjective well-being by adapting and implementing in a rural area with high longevity indicators (longer and healthier life expectancy compared to the rest of the country), a learning intervention previously evaluated in Costa Rica with urban older adults (Castro-Rojas, 2021). The study also evaluated the relevance of including, during the learning process, some strategies for coping with anxiety and stress when interacting with ICT: training grounded on mindfulness-based cognitive therapy (MBCT) (Crane, 2009); and group sessions for reflecting on digital inclusion of the older population.

Using a pretest and post-test design, the study describes and compares the improvements in cognitive abilities and subjective well-being in two groups of older adults. Both Group 1 ($n$ = 11) and Group 2 ($n$ = 12) participated in a 9-week blended learning experience using ICT devices and applications in daily life for stimulating autobiographical memory and social interaction. Additionally, Group 1 received training on coping strategies based on MBCT whereas Group 2 reflected on the digital inclusion of older people.

The study was implemented in Nicoya, Guanacaste, a community in the northeast of the country with a higher proportion of octogenarians, nonagenarians and centenarians compared to the rest of the country (Rosero-Bixby et al., 2013) and described as a mainly rural area based on population density, infrastructure and access to goods and services (INEC, 2016).

The results in each group are discussed, as well as the feasibility and limitations of this type of community intervention. This article presents the quantitative evaluation of the learning intervention. Additionally, a subsequent qualitative study, also part of the same project, explored what the intervention elements were positively evaluated by the participants and some suggestions for improvement. This complementary qualitative perspective provides valuable insights into the user experience and informs future iterations of the intervention.

## MATERIALS AND METHODS

### General design

Following a case study approach by focusing on a few instances of a particular phenomenon and with the end of providing and in-depth account of processes (Descombe, 2014) the study implemented a non-randomized group design and a pre-and post-test approach with two versions of the learning intervention. Participation was voluntary and given the sanitary restrictions by COVID-19, older people showed reservations to participate in group activities. As a result, the groups were intentionally conformed, and the participants were assigned to each group based on criteria of availability and convenience. In addition, considering time and resource limitations, when the first group was formed, the Learning Intervention 1 was implemented and when the number of participants for the second group was completed, the Learning Intervention 2 was executed. Consequently, these limitations led to differences between the groups that will be exposed in the results section.

Group 1 ($n$ = 11) participated in Learning Intervention 1, which included strategies and practices for: learning and using ICT devices and applications; reminiscence activities to stimulate autobiographical memory and social interaction with peers; plus, strategies for coping with stress and anxiety based on MBCT. Group 2 ($n$ = 12) participated in Learning Intervention 2, which included the same content as Learning Intervention 1 but instead of training on coping strategies they reflected on digital inclusion of the older population.

The primary hypothesis was that participants in both groups would improve their baseline indicators of cognitive abilities and subjective well-being after the learning intervention. The study also explored if there were different effects between both groups.

As proposed by the case study approach the study was implemented in a naturalistic setting and multiple sources of data were included (Descombe, 2014).

### General description of the learning intervention

The 9-week learning intervention included learning activities for using basic features of a Samsung tablet, mobile data and wireless Internet connections (Wi-Fi hotspots at home or public venues). Using WhatsApp (WA) features (customize user profile; add new contacts; join a group; create and send pictures and audio; search and comment media files; reply to a specific post/message) and Zoom (join a meeting; use the toolbar on the screen: mute/unmute, start video/stop video, chat, leave and gallery view). It also included activities of a reminiscence protocol (Salazar-Villanea, 2010) for stimulating autobiographical

memory, which has been associated with creating empathy among groups and improvements in cognitive abilities and general well-being in older adults (Westerhof et al., 2010).

The participants shared, through text, audio and/or images on WA, personal stories about "vacation and holidays", "school time and/or training" and "games and friendship". The stories (reminiscences) followed a list of memory cues to help participants create more specific memories related to themselves. The participants commented and fed back the reminiscences of their companions both in the WA group and in the face-to-face sessions.

Additionally, the Group 1 training in coping strategies consisted of eight 2-hour workshops (one per week) facilitated by Zoom. Content included tools to identify cognitive, emotional, physiological, and behavioural manifestations related to anxiety and stress, and techniques to reduce their negative effects. Mindfulness techniques include cognitive components (full attention) and physiological (changes in physiological responses), emotional (attitude towards life), and philosophical (human beings and their reality) aspects (Crane, 2009; Kabat-Zinn, 1994). Such content can be adapted to any situation in daily life, but during the project, it was associated with older adults' ICT interactions, and COVID-19 coping strategies.

On the other hand, Group 2 reflected on digital inclusion which comprised eight 2-hour sessions (one per week) facilitated by Zoom that discussed: opportunities and barriers for learning about and using ICT; ICT-learning interests and needs; ICT-learning design for older people; skills and abilities required by ICT facilitators (teachers); myths and stereotypes about older adults; and social support for ICT learning. Figure 1 presents a schema of the learning intervention for both groups.

**Figure 1.** Schema of the learning intervention for both groups

| Week # | Monday | Wednesday | Friday * |
|---|---|---|---|
| 1 | **Individual pretest - session** | | |
| 2 | Face to face Session | Face to face Session | Synchronous session by Zoom |
| 3 | Asynchronous learning | | Synchronous session by Zoom |
| 4 | Face to face Session | Face to face Session | Synchronous session by Zoom |
| 5 | Asynchronous learning | | Synchronous session by Zoom |
| 6 | Face to face Session | Face to face Session | Synchronous session by Zoom |
| 7 | Asynchronous learning | | Synchronous session by Zoom |
| 8 | Face to face Session | Face to face Session | Synchronous session by Zoom |
| 9 | **Individual post-test session** | | |

* Group 1: training on strategies for coping with anxiety and stress; Group 2: reflecting on digital inclusion for older adults.

The project provided each participant with one tablet (Samsung Galaxy A7 Lite, 8.7", 32 GB) and an Internet SIM card that they returned at the end of the learning intervention. Face-to-face sessions were conducted at the public library in the city centre of Nicoya and the project provided transportation subsidies to the participants.

The Universidad Nacional, Costa Rica ethical board, approved the study and the older adults gave their written consent before participating in the study.

## Participants

The study recruited older adults from the databases of previous studies and a general call to the public library of Nicoya. Participants met the following inclusion criteria: older than 60 years; Mini-Mental State Examination (MMSE) score ≥ 24; able to read and write; little experience with ICT; no diagnosis of psychiatric, neurological, or neuropsychological disorders; and no present sensory and/or motor deficits affecting the use of a tablet.

## Procedure

During Week 1 of the intervention, the inclusion criteria were verified, and each participant individually completed the pretest measures for cognitive performance and subjective well-being. In Week 2, participants received the tablet and SIM card and began the learning intervention described in Figure 1; the researchers facilitated all the learning activities. Each week the participants received printed learning material with the learning content. At Week 8, participants evaluated the intervention as a group, and individually completed an online evaluation form. At Week 9, each participant individually completed the post-test measures. All the activities took place in the public library of Nicoya.

## Complementary Qualitative Data Collection (Participatory Workshop)

Four months after the completion of the learning intervention, a participatory design (PD) workshop was conducted with 20 older adults who had previously participated in the intervention. This qualitative component aimed to gather in-depth feedback and suggestions from the end-users' perspective. The workshop involved activities oriented towards reflecting on the participants' experience and gathering input for improving the three core learning activities (LA) (LA1: Learning about technology, LA2: Reminiscences, LA3: Synchronous online workshops). Participation was recorded through audio. The audio and transcripts were analyzed using a thematic analysis procedure. This involved reviewing the data to identify emergent themes and organizing them into categories and subcategories (Braun & Clarke, 2006). This qualitative component provides rich, participants centered data complementing the quantitative outcomes, addressing the need for deeper insights into participants´ experience, particularly valuable given the pilot nature and sample size of the quantitative study. For a comprehensive analysis of the qualitative findings, please refer to Castro-Rojas and Coto-Chotto (2025).

## Data collection methods

### Cognitive measures

- Screening/MMSE (Folstein et al., 1975) to assess orientation, immediate memory, attention, calculation, language, and constructive praxis.
- Stroop test (Golden, 1974) to evaluate cognitive flexibility and resistance to interference from external stimuli.

- Trail Making A and B tasks (Kortte et al., 2002) to measure cognitive flexibility and the ability to maintain a complex response and sustain attention.
- Wechsler Adult Intelligence Scale (WAIS) block design test (Wechsler, 1981) to measure visuospatial constructional ability.

### Subjective well-being measures

- Short Form-8 (SF-8) Health Survey Questionnaire (Ware et al., 2001) to evaluate perceived health, with eight items asking participants to rate whether their health was "poor" (1) to "excellent" (5) and about their current physical health.
- Satisfaction with Life Scale (SWLS; Diener et al., 1985) to assess subjective well-being, concentrating on measuring global life satisfaction.
- Positive and Negative Affect Scale (PANAS; Watson et al., 1988) to measure emotional stability as an initial tool for assessing the emotional state.
- Center for Epidemiologic Studies Depression Scale (CES-D-10; Andresen et al., 1994) to evaluate depression in older adults.
- Perceived Stress Scale (Cohen et al., 1983) to measure perceived stress.
- Generalized Anxiety Disorder Scale (GAD-7; Spitzer et al., 2006) to evaluate experiencing several generalized anxiety symptoms.
- Functional Social Support Questionnaire (DUKE-UNC; Bellón et al., 1996) to measure the degree of perceived social support.

### Health record measures

History of cardiovascular disease, diabetes, obesity, smoking, alcoholism, stroke or arteriosclerosis was recorded for each participant.

### Sociodemographics

Gender (male, female), chronological age report, years in formal education and income were recorded.

## Data analysis

The sample was characterized by descriptive analysis using means and standard deviations (SD) or percentages. Cognitive and subjective well-being outcomes were reported as means (SD) and ranges.

For each group, comparisons of outcomes between pre- and post-intervention assessments (within-comparison) or by group (between-comparison) were performed using paired and unpaired Student's *t*-tests or Wilcoxon-Mann-Whitney tests (for non-normal distributions) and one-way ANOVAS to seek cognitive performance differences by educational level in both groups. Given this study's small sample size, there was a high probability of finding non-significant differences when comparing the two groups (between-comparison). Therefore, to assess the magnitude and direction of intervention outcome, effect

size (ES) was computed in the form of Cohen's *d*. ES can be considered small ($d = 0.2$), medium ($d = 0.5$) or large ($d = 0.8$) (Cohen, 1988).

The significance level used for all statistical tests was set at 0.05. Data were processed using the statistical package SPSS v.25 (IBM, 2017).

## RESULTS

Eleven participants were allocated to Group 1 and twelve to Group 2. Due to the characteristics of the recruitment process, Group 1 was formed mainly for housewives and Group 2 presented more retired workers. Table 1 presents the sociodemographic characteristics of the sample. There was no significant group difference in age, gender, MMSE score, or monthly income in the baseline assessment ($p > 0.05$) and only years of formal education showed significant differences (Group 1: $M = 9.64$; Group 2: $M = 12.82$; $t_{(21)} = 2.22$, $p = 0.037$). We ordered the education level into three categories: 1. Low level (primary), 2. medium level (high school), and 3. high level (technician or university studies) for comparison purposes.

**Table 1.** Participants´ characteristics

| Sociodemographics | Group 1 | Group 2 |
|---|---|---|
| ***Male*** | 0 | 2 |
| ***Female*** | 11 | 10 |
| **Average age (years)** | 74.45 | 73.42 |
| SD | 4 | 6.11 |
| (Min-Max) | (68-81) | (60-81) |
| **Educational level** | | |
| *Low %* | 18.18 | 16.67 |
| *Medium %* | 54.55 | 25.00 |
| *High %* | 27.27 | 58.33 |
| *Average of years in formal education* | 9.64 | 12.82 |
| **Monthly income** | | |
| *No income %* | 18.20 | 8.33 |
| *Less than $600 %* | 45.45 | 41.67 |
| *Between $600–$1600 %* | 36.36 | 50 |
| **Pension income %** | 54.55 | 83.33 |
| ***Average of p*eople living in the same household** | 2.09 | 2.17 |
| SD | 1.30 | 1.64 |
| (Min-Max) | (1-5) | (1-7) |

None of the participants discontinued the intervention. Only one participant in Group 1 did not perform the post-test assessment, resulting in eleven subjects for the final analyses.

### Cognitive outcomes

Group 2 showed better scores in the cognitive tests at the baseline. Table 2 presents a comparison of both groups at pre- and post-test measurement. The comparisons showed a trend of stability of cognitive indicators and screening measures, executive function, and visuospatial abilities in general. After the intervention, in Group 1, there was a significant improvement in performance on the Trail-Making-A Time task ($p = 0.011$) and Stroop Words task ($p = 0.002$). In Group 2, only the Trail-Making-B Time task indicated an improvement

($p$ = 0.05). There was a tendency for improvement in both groups after intervention despite not showing significant differences in other cognitive indicators. These results indicate improvement in executive functions such as processing speed, selective attention, and inhibition of irrelevant information, which are key abilities for performing activities of daily living.

**Table 2.** Comparisons within-groups of the cognitive functioning indicators in pre and post-test

| Groups | Indicators | Mini-Mental | | Trial Making A Time | | Trial Making A Errors | | Trial Making B Time | | Trial Making B Errors | | Cube | | WAIS | Stroop Word | | Stroop Color | | Stroop Interference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test time | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | | Pre | Post | Pre | Post | Pre | Post |
| 01 | Media | 27.82 | 26.82 | 99.74 | 84.44 | 2.18 | 0 | 259.5 | 269.36 | 12.55 | 7.18 | 15.55 | 16.64 | | 59.45 | 71.55 | 49.18 | 48.82 | 20.36 | 22.55 |
| | SD | 2.089 | 2.18 | 41.74 | 36.29 | 5.78 | 0 | 69.97 | 51.51 | 11.62 | 6.58 | 11.01 | 10.83 | | 19.38 | 14.08 | 12.73 | 9.4 | 8.46 | 9.09 |
| | *t-test* | - | - | $T_{(10)}$=3.127, p=.011 | | - | - | - | - | - | - | - | - | | $t_{(10)}$=4,066, p=.002 | | - | - | - | - |
| 02 | Media | 27.67 | 28.08 | 90.91 | 75.08 | 0.25 | 0.8 | 240.1 | 211.58 | 4.83 | 4.00 | 17.75 | 17.33 | | 69.92 | 76.75 | 48.00 | 50.67 | 26.08 | 28.67 |
| | SD | 2.14 | 1.56 | 40.25 | 39.72 | .45 | 0.3 | 76.85 | 51.51 | 6.5 | 5.68 | 7.46 | 6.69 | | 17.5 | 15.46 | 10.81 | 6.67 | 5.12 | 7.25 |
| | *t-test* | - | - | - | - | - | - | $t_{(11)}$=2.11, p=.05 | | - | - | - | - | | - | - | - | - | - | - |

*Note*: We only show significant *t-values* at $p$=0.05

## Socio-emotional outcomes

Table 3 presents the outcomes from socio-emotional measures in both groups. Stability was found in pre- and post-intervention measures for most of the positive socio-emotional indicators, such as life satisfaction, social support, self-efficacy, and perceived health, which were scored at medium levels in all cases. Negative emotional variables evidenced a similar pattern: variables such as stress and depression were positioned at medium to low scores in both pre-and post-test measures without showing significant differences after the intervention but with a tendency to decrease in the post-test evaluation. Finally, significant differences indicating a decrease were found in the indicator of depression in both Group 1 ($p$ = 0.63) and Group 2 ($p$ = 0.013). The positive emotion indicator (PANAS-P) increased in Group 2 ($p$ = 0.005). Most positive well-being indicators remained stable after the intervention in both groups, and some showed a tendency to improve.

**Table 3.** Comparisons within-groups of the socio-emotional indicators in pre and post-test

| Groups | Indicators | LS | | Stress | | Anxiety | | Depression | | SE | | PH | | PANASP | | PANASN | | SS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test time | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 01 | Media | 3.36 | 3.4 | 3.09 | 2.99 | 1.94 | 2.1 | 2.11 | 1.88 | 3.79 | 3.46 | 2.64 | 2.75 | 4.21 | 4.05 | 2,19 | 2,47 | 4,01 | 3,71 |
| | SD | 0.75 | 0.59 | 0.57 | 0.48 | 0.55 | 0.67 | 0.75 | 0.46 | 0.67 | 0.76 | 0.8 | 0.76 | 0.54 | 0.52 | 0,89 | 0,77 | 0,75 | 1,04 |
| | *t-test* | - | - | - | - | - | - | $t_{(10)}$=2.09, p=.063 | | - | - | - | - | $t_{(10)}$=2.32, p=.042 | | $t_{(10)}$=-2.59, p=.027 | | - | - |
| 02 | Media | 3.45 | 3.60 | 3.08 | 2.92 | 1.84 | 1.82 | 2.05 | 1.69 | 3.78 | 4.00 | 2.63 | 2.24 | 3.69 | 4.20 | 2.40 | 2.05 | 4.04 | 4.23 |
| | SD | 0.69 | 0.67 | 0.50 | 0.34 | 0.64 | 0.54 | 0.63 | 0.40 | 0.60 | 0.42 | 0.96 | 0.76 | 0.55 | 0.38 | 1.06 | 0.68 | 0.83 | 0.71 |
| | *t-test* | - | - | - | - | - | - | $t_{(11)}$=2.94, p=.013 | | - | - | - | - | $t_{(11)}$=-3.49, p=.005 | | - | - | - | - |

*Note* : LS: Life Satisfaction. SS= Social Support. SE= Self-efficacy, PH= Perceived Health. We only show significant *t*-values at $p$=0.05

In Group 1 there was a decrease in positive emotions (PANAS-P: $p$ = 0.042) and a marginal increase in negative emotions (PANAS-N: $p$ = 0.027), which can be related to lack of experience in learning and using ICT, the educational level of this group and to cognitive demands from the training in coping strategies, this will be discussed further in the discussion section.

## Cognitive abilities: Between-group comparisons

It should be noted that there was a tendency for better performance in Group 2 than Group 1, both in the pre-and post-intervention cognitive measures. At the baseline assessment, the ES was different in most of the indicators and Group 2 showed better performance in Trail-Making-A Time ($d$ = 0.21), Trail-Making-A Errors ($d$ = 0.47), Trail-Making-B Time ($d$ = 0.26), Trail-Making-B Errors ($d$ = 0.81), WAIS Cube task ($d$ = 0.23), Stroop Words task ($d$ = 0.56) and Stroop Interference task ($d$ = 0.81). Post-intervention comparison showed a significant difference in the Trail-Making-B Time task ($p$ = 0.047, $d$ = 0.88), with better performance in Group 2 than Group 1; a similar trend was observed in the other cognitive indicators, with small to medium ES in the MMSE ($d$ = 0.66), Trail-Making-A Time ($d$ = 0.24), Trail-Making-A Errors ($d$ = 0.51), Stroop Words task ($d$ = 0.35), Stroop Colour task ($d$ = 0.22) and Stroop Interference task ($d$ = 0.74). It should be noted that the cognitive indicators used are sensitive to formal educational differences such as those existing between the groups compared (see Table 4).

**Table 4.** Comparisons between-groups of cognitive functioning indicators in pre and post-test

| Time | Indicators | Mini-Mental | | Trial Making A Time | | Trial Making A Errors | | Trial Making B Time | | Trial Making B Errors | | Cube | | WAIS | | Stroop Word | | Stroop Color | | Stroop Interference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Groups** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** |
| | **Media** | 27.82 | 27.67 | 99.74 | 90.92 | 2.18 | .25 | 259.4 | 240.2 | 12.55 | 4.83 | 15.55 | 17.75 | 59.45 | 69.92 | 49.18 | 48.00 | 20.36 | 26.08 | | |
| **Pre-** | **SD** | 2.08 | 2.14 | 41.74 | 40.25 | 5.77 | .45 | 69.9 | 76.8 | 11.62 | 6.59 | 11.01 | 7.46 | 19.38 | 17.50 | 12.73 | 10.81 | 8.46 | 5.12 | | |
| **test** | ***t-test*** | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| | ***Cohen's d*** | 0.07 | | 0.21 | | 0.47 | | 0.26 | | 0.81 | | 0.23 | | 0.56 | | 0.09 | | 0.81 | | | |
| **Post-** | **Media** | 26.82 | 28.08 | 84.44 | 75.08 | 0.0 | 0.8 | 269.4 | 211.6 | 7.18 | 4.00 | 16.64 | 17.33 | 71.55 | 76.75 | 48.82 | 50.67 | 22.55 | 28.67 | | |
| **test** | **SD** | 2.18 | 1.56 | 36.29 | 39.73 | 0.0 | .28 | 51.54 | 75.99 | 6.58 | 5.68 | 10.83 | 6.69 | 14.08 | 15.46 | 9.40 | 6.67 | 9.09 | 7.25 | | |
| | ***t-test*** | - | - | - | - | - | - | $T_{(21)}$=2.11, p=.047 | | - | - | - | - | - | - | - | - | - | - | | |
| | ***Cohen's d*** | 0.66 | | 0.24 | | -- | | 0.88 | | 0.51 | | 0.07 | | 0.35 | | 0.22 | | 0.74 | | | |

*Note*: We only show significant *t-values* at $p$=0.05

We ran a one-way variance analysis to test educational level differences between groups' cognitive performance at the pre and post-test. Education was ordered into three categories: 1. Low level (primary), 2. medium level (high school), and 3. high level (technician or university studies).

In groups 1 and 2, 8.7% of the sample had a low educational level, 26% in group 1 had a medium level, and in group 2, 13%. A high academic level in group 1 represented 13%, and in group 2, 30.4%.

The ANOVA found that the block design test significantly differed from the pre-test in both groups ($F_{(2,20)}$ = 9.76, p. 0.001, $\eta^2$= 0.49) by educational level. The difference was found between the medium level and high level by a post hoc analysis made with the Bonferroni correction ($t_{(20)}$ = 4.4, p< .001, IC 95=-3,19 to -0.85).

Also, we found a significant difference in the Trail Making B task by educational level in both groups from the pre-test ($F_{(2,20)}$ = 5.10, p. 0.016, $\eta^2$= 0.34). As before, by a post hoc analysis made with the Bonferroni correction, we found differences by educational level between low and high levels ($t_{(20)}$ =2.64, p=0.047, IC 95=0.23 to 2.90), and very similar by medium and high levels ($t_{(20)}$ = 2.64, p=0.047, IC 95=0.17 to 2.25).

Finally, we found a significant difference in the Trail Making B task by educational level in both groups from the post-test ($F_{(2,20)}$ = 8.87, p = 0.002, $\eta^2$= 0.47). A post hoc analysis

with the Bonferroni correction found differences by educational level by medium and high levels ($t_{(20)}$ =4.16, p=0.001, IC 95=0.76 to 3.06).

## Socio-emotional variables: Between-group comparisons

Most of the socio-emotional variables showed no significant differences and the evidence indicated stability in both groups at the pre- and post-test assessments. However, in the pre-intervention measures there was a significant difference in positive emotion indicator PANAS-P, favouring Group 1 ($p$ = 0.031, $d$ = 0.95); and with a small ES in negative emotion indicator PANAS-N ($d$ = 0.21), Group 1 also showed fewer negative emotions than Group 2. Nevertheless, the same indicators at the post-intervention assessment showed an inverted trend: Group 2 was observed with less negative emotions than Group 1 (medium ES, $d$ = 0.57) and more positive emotions than Group 1 (small ES, $d$ = 0.33). At the post-intervention assessment, Group 2 showed better scores in other socio-emotional variables, such as higher life satisfaction level (small ES, $d$ = 0.31), low anxiety (medium ES, $d$ = 0.46), less depression (medium ES, d =0.44), better perceived health (medium ES, $d$ = 0.67) and higher scores in social support (large ES, $d$ = 0.85) and self-efficacy beliefs ($p$ = 0.046; large ES, $d$ = 0.89; see Table 5).

**Table 5.** Comparisons between-groups of the socio-emotional indicators in pre and post-test

| Time | Indicators | LS | | Stress | | Anxiety | | Depression | | SE | | PH | | PANASP | | PANASN | | SS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Groups** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** | **01** | **02** |
| | **Media** | 3.36 | 3.45 | 3.09 | 3.08 | 1.94 | 1.84 | 2.11 | 2.05 | 3.79 | 3.78 | 2.64 | 2.63 | 4.21 | 3.69 | 2.19 | 2.40 | 4.01 | 4.04 |
| | **SD** | .75 | .69 | .57 | .50 | .55 | .64 | .75 | .63 | .75 | .83 | .80 | .96 | .54 | .55 | .89 | 1.06 | .75 | .83 |
| **Pre-test** | ***t-test*** | - | - | - | - | - | - | - | - | - | - | - | - | $t_{(21)}$=2.30, p=.031 | | - | - | - | - |
| | ***Cohen's d*** | 0.12 | | 0.01 | | 0.16 | | 0.08 | | 0.01 | | 0.01 | | 0.95 | | 0.21 | | 0.03 | |
| | **Media** | 3.40 | 3.60 | 2.99 | 2.92 | 2.10 | 1.82 | 1.88 | 1.69 | 3.46 | 4.00 | 2.75 | 2.24 | 4.05 | 4.20 | 2.47 | 2.05 | 3.71 | 4.23 |
| | **SD** | .59 | .67 | .48 | .34 | .67 | .54 | .46 | .40 | .76 | .42 | .76 | .76 | .52 | .38 | .77 | .68 | .76 | .42 |
| **Post-test** | ***t-test*** | - | - | - | - | - | - | - | - | $t_{(21)}$=-2.1, p=.046 | | - | - | - | - | - | - | - | - |
| | ***Cohen's d*** | 0.31 | | 0.16 | | 0.46 | | 0.44 | | 0.89 | | 0.67 | | 0.33 | | 0.57 | | 0.85 | |

*Note*: LS: Life Satisfaction. SS= Social Support. SE= Self-efficacy, PH= Perceived Health. We only showed significates $t$-values at $p$=0.05

These results suggest that Group 2 benefited the most from the intervention, which can be related to their better educational level and therefore more access to ICT devices and applications in their daily life.

## Participants´ evaluation of the learning intervention

The general experience of the participants was significant, and attendance was almost 100% in all the sessions, which demonstrated enthusiasm and commitment to learning.

Regarding the content and activities carried out, in a customized questionnaire 80% of participants indicated that reminiscences (recovering and narrating personal memories) were the most significant activity for them, followed by using Zoom (76%) and recording and sharing audios in WA (76%). When asked about the learning that they can integrate into their daily lives, 80% mentioned calls and video calls in WA. It is interesting to note that 77% of Group 1 participants considered that what they learned in the training for coping with anxiety and stress was very useful for their daily lives.

The intervention also generated a change in attitudes towards ICT, with 84% indicating that they had incorporated some of the learning into their daily lives, 76% feeling more

comfortable interacting with ICT, 84% discovering that they are able to use technology and 100% becoming aware of aspects related to technology that they would like to continue learning.

Furthermore, all the participants showed a high degree of satisfaction with the facilitators, content, learning materials, and activities during the sessions.

## Qualitative findings from the participatory workshop

Twenty (20) participants actively engaged in the workshop, with most understanding the tasks and offering valuable feedback and suggestions about the intervention. Their contributions complemented the satisfaction reported in the quantitative evaluation by providing concrete details on what worked well and what could be enhanced from their perspective. Participant feedback focused primarily on familiar aspects of the intervention, such as the location and format of sessions, teaching-learning strategies, learning materials, and the role of facilitators. Fewer suggestions were provided regarding novel or creative elements, or specific improvements to the ICT tools/functionalities themselves, possibly due to limited prior experience with technology.

The results are illustrated with verbatim transcriptions of the participants´ contributions.

Specific feedback included a preference for in-person sessions and more time for practicing the learned skills. They found the library facilities suitable. They also desired a greater number of sessions. The ease of resolving doubts and requesting help in person was a significant factor.

“I believe there could be more live classes initially, and over time, a gradual transition to virtual sessions.” (Participant 3, November 24, 2022)

Related to teaching-learning strategies suggestions pointed to the need for more in-depth explanations of ICT use. They also emphasized the importance of having time and opportunities for hands-on practice.

“More time for reflection is needed - allowing more space at the end of the class to synthesize newly acquired knowledge.” (Participant 2, November 24, 2022)

About learning materials, participants suggested that materials should be visually attractive and multimedia (combining printed, digital, audio, and video formats). They also highlighted the need for materials adapted for individuals with visual difficulties, such as larger text.

“To improve the learning materials, in addition to the printed booklet, it would be helpful to include a recording for review at home - perhaps an audio file for listening.” (Participant 2, November 24, 2022)

The support provided by the facilitators was highly appreciated, characterized by kindness and patience. Participants expressed satisfaction with the facilitators' performance and personal characteristics.

“All the support provided was excellent, and the way the content was delivered - with great care and sensitivity to our individual differences - was deeply appreciated.” (Participant 1, November 24, 2022)

Participants also highlighted the value of the reminiscence activities for social interaction and sharing experiences. The topics covered were also well-received, as was the ability to share audio or text reminiscences via WhatsApp. They also suggested more topics:

“Topics could be more closely related to older adults, for instance, addressing issues such as widowhood.” (Participant 4, November 24, 2022)

Related to the most important learnings, four months after the intervention concluded, the older adults continued to value the knowledge gained, particularly regarding ICT use in daily life. Therefore, 75% of participants considered the face to face sessions focused on learning about ICT the most relevant component of the intervention. Particularly, they enjoyed the in-class practice, the facilitators, and the support provided during sessions. This activity was also where they reported learning the most.

About using technological tools, 70% of participants were still using 8 out of the 10 technological tools and applications they learned about. Participants particularly valued the ability to use WhatsApp functionalities in their social interactions.

Participants expressed interest in continuing to learn more applications, especially using their mobile phones, which are the devices most owned and easily carried.

Among the online workshops, the "Reflections on digital inclusion” workshop (Group 2) was significantly more liked than the "Training on coping strategies" (Group 1). Participants in the digital inclusion workshop especially appreciated the facilitators' role and the technical support received during Zoom sessions.

As observed the participants focused on the how of learning (methodology, support, environment, materials) rather than the what (specific applications or content). This indicates that while the tools and general topics were relevant, the learning process is always subject to refinement. Overall, the qualitative data provided specific, actionable feedback from the participants, enriching the understanding of the intervention's impact and guiding future design iterations in a participant-centered manner. An in-depth discussion of the qualitative outcomes can be found in (Castro-Rojas & Coto Chotto, 2025).

## DISCUSSION

The aim of this study was to evaluate the effectiveness of a learning intervention mediated by ICT on the cognitive abilities and subjective well-being of older adults residing in a rural area of Costa Rica with high longevity indicators such as longer life expectancy and lower risks of disease during the old age compared to the rest of the country (Rosero-Bixby et al., 2019).

The intervention was implemented during the last phase of COVID-19 pandemic which remarked the relevance of digital inclusion of older adults (Nimrod, 2021; Roe et al., 2021; Seifert, 2021). The results indicated that both modalities of the learning intervention were

highly feasible and acceptable for the participants, as indicated by the participants´ high assistance and no dropouts. The intervention was highly appreciated by participants because they perceived that it met their needs for cognitive stimulation, social interaction, and digital inclusion. The participants showed high motivation during all sessions and expressed a desire to continue learning about and using ICT. Developing the intervention in the community library supported the right of participants to "age in their place" (WHO, 2015).

For both modalities of the intervention, stability was observed in most of the indicators of cognitive abilities and subjective well-being at pre- and post-intervention assessment. However, there were significant improvements after the intervention in the Trail-Making-A Time task and Stroop Words task in Group 1 and in the Trail-Making-B Time task in Group 2, which supports the potential of this type of intervention to enhance cognitive performance during old age, particularly in abilities related to executive functioning (Djabelkhir et al., 2017; Halmdienst et al., 2019; Morrison & McCutheon, 2019; Ryd et al., 2018).

The between-group comparisons and ES analysis showed that Group 2 displayed better performance in cognitive abilities at both pre- and post-intervention assessments. As mentioned in the results section, all the cognitive indicators assessed were sensitive to formal educational differences, such as those existing between the groups. It has been noted that the contribution of education to cognitive reserve in old age is a criterion of optimal performance in cognitive function (Wilson et al., 2019). Differences on cognitive tests scores were found between lower and/or intermediate and high educational level, since group two had more participants with high levels of education, that could explain the better performance in group 2. These results indicated that the cognitive reserve and cognitive demand of the planned learning activities are key aspects to take into consideration when designing ICT interventions aimed at improving cognitive abilities in older adults. In future studies, an equivalent group design can help to clarify these results.

Both groups showed improvements in positive socio-emotional measures after the intervention and a reduction of negative socio-emotional indicators, as expected (Diaz-Lopez et al., 2016; Djabelkhir et al., 2017; Hur, 2016; Ryd et al., 2018). There was improvement in the depression indicator for both groups and an improvement in positive emotions for Group 2. The between-group comparisons and ES analysis showed larger effects for Group 2 than Group 1, this could be related to sociodemographic variables such as educational level, and occupation: Group 1 participants were primarily housewives and some of them worked in the industry services, whereas Group 2 were retired workers and some of them were educators and had qualified jobs which could be related to a more active social life. More research is needed to clarify these aspects.

Group 1 showed a decrease in positive emotions and a marginal increase in negative emotions; a possible explanation for this is lack of experience using Tablets, WA and Zoom applications, it is also possible that the training for coping with anxiety and stress may have been overly demanding for Group 1 because it was developed totally by Zoom and included the use of self-report instruments and at-home tasks that involved additional cognitive demands. It is important to note that the low educational level of this group could also have an influence on the way they face cognitive challenges.

Another important consideration is that the MBCT training techniques included meta-cognitive components, which could expose Group 1 to a self-assessment process of their emotional situation that increases their consciousness of daily life stressor events (Crane,

2009; Kabat-Zinn, 1994) and their emotional responses when using ICT and to COVID-19 environment. In Group 2 these effects did not exist.

The evidence showed that both versions of the learning intervention can support cognitive enhancement and subjective well-being because both groups showed stability of overall cognitive performance and improvements in cognitive abilities associated with executive functioning, as well as improvements in well-being indicators. The study results indicate that people with higher educational levels benefit the most from the intervention (Wilson et al., 2019), which poses a challenge for designing suitable interventions for people with low educational level and low incomes living in rural areas.

Regarding the content and activities focused on stress management when interacting with ICT, the improvements in both groups indicate that both modalities (training on coping strategies and reflecting on digital inclusion of the older population) can be beneficial for older ICT learners, as both are opportunities to elaborate thoughts and emotions emerging during the ICT learning process. Future studies must take into consideration the additional cognitive demand from training on stress coping strategies.

Both modalities of the learning intervention support the enhancement of cognitive abilities and subjective well-being, but further research is needed to distinguish specific effects related to ICT learning and use, reminiscence activities and training strategies for coping with anxiety and stress when interacting with ICT.

The quantitative findings on the intervention's feasibility and acceptability are significantly enriched by the qualitative data obtained from the participatory workshop. The workshop allowed participants to articulate why they valued certain aspects of the intervention, such as the library's familiar community environment, the kindness and patience of the facilitators, and the opportunities for social interaction, especially during reminiscence activities.

These qualitative insights underscore the importance of human and environmental factors, not just technological aspects, in the success of ICT learning interventions for older adults. The feedback gathered through the participatory workshop provides practical guidance for future iterations of the intervention, highlighting user preferences for blended modalities with a strong emphasis on in-person support and practice, diverse and accessible learning materials, and continuous assistance.

## CONCLUSIONS

Both modalities of the intervention have the potential to improve cognitive abilities such as processing speed, selective attention and inhibition of irrelevant information, decrease depression indicators and increase positive indicators of subjective well-being in older adults without cognitive impairment. The study results highlight the need to continue studying the effectiveness of community interventions using ICT to facilitate cognitive activity and well-being. Furthermore, both intervention modalities (training in stress coping strategies and reflecting on digital inclusion of older people) were feasible and well accepted by the participants.

Based on the motivation and commitment of older people, community interventions using ICT aimed at facilitating cognitive activity and subjective well-being are an opportunity

to implement effective and low-cost interventions to promote healthy ageing and prevent decline during old age. Community interventions have the potential to reach older adults in their daily living environments. Using ICT devices and applications allows participants to perform activities and tasks at any time and place they wish, and they do not always require the presence of an instructor. Thus, these interventions are effective, flexible, and more affordable because they do not require so many human resources.

Replicating this type of intervention on a large scale can result in the inclusion of populations that would otherwise not receive any intervention and would be digitally excluded. Furthermore, there is a need for more studies with active control groups that allow comparisons with other types of interventions. Future research should therefore include larger and more diverse samples.

Beyond the quantitative outcomes, the qualitative study using participatory design provided critical insights into the user experience and practical suggestions for improving the intervention from the perspective of older adults. Key elements to consider for future iterations and similar interventions include ensuring sufficient hands-on practice time, providing continuous and empathetic support from facilitators, and offering diverse and accessible learning materials.

## LIMITATIONS

The main limitations of the study were sample size and the non-randomized assignation of the participants to each intervention group, which reduced the probability to test the interventions effects. However, this was a pilot study, and it will be necessary to adjust the protocol of the intervention for future studies. Participants in this study were highly motivated to learn about and use ICT which limits the generalization of the research findings to similar learners. More studies are needed to evaluate the effectiveness of this approach for older people with low willingness to learn about and using ICT. Furthermore, the participatory design activities in the workshop were limited in scope (focusing primarily on improvement evaluation rather than generative design) and duration, potentially limiting the depth and novelty of the suggestions provided by participants. The sample for both components was predominantly female, limiting broader gender representation.

## IMPLICATIONS FOR APPLICATION

Community-based interventions using ICT to promote cognitive activity and subjective well-being are suitable for older adults and public institutions in rural areas with high longevity indicators. Therefore, these types of interventions are an opportunity to implement effective and low-cost strategies to promote healthy ageing and prevent decline during old age. The study results indicated that people with a greater reserve benefit the most from the intervention, which poses a challenge for designing suitable interventions for people with low educational level and low income living in rural areas. Practitioners can collaborate in the design and implementation of these strategies aimed to meet older people needs and interests.

The findings, particularly from the qualitative participatory design component, offer practical implications for practitioners and researchers designing and implementing ICT learning interventions for older adults. It is crucial to tailor learning activities and materials to the specific needs and diverse abilities of older adults, ensuring clarity of instructions and ample opportunity for hands-on practice and personalized support. Community spaces like public libraries are suitable and comfortable environments for these interventions in Costa Rica. The insights gained from participants are valuable for creating interventions that are not only effective but also relevant, acceptable, and empowering for older adults

## Conflicts of Interest

The authors report no conflicts of interest in this work.

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# WHAT'S IN A BOT? TRACING EPISTEMIC DIFFERENCES ACROSS EXPERT DISCOURSES

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Abstract: *Automated social social agents -bots – are increasingly central to digital environments, yet definitions of what constitutes a bot vary across expert communities. This article analyses how bots are conceptualised in academic and technological discourse by examining scholarly publications (Scopus) and developer discussions (Stack Overflow). Using computational methods, including keyword-in-context analysis and topic modelling, we trace epistemic differences in bot definitions across disciplines. Findings reveal structural discursive silos, with technical fields emphasising functional properties and social sciences focusing on sociotechnical entanglements. These definitional divergences have implications for research, regulation, and governance in an era of AI-driven automation.*

Keywords: *Social bots, discourse, expert communities, text analysis, AI.*


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## INTRODUCTION AND AIM

The increased use and occurrence of automated social media accounts – bots – in online communication has given rise to an increased need to be able to distinguish bot accounts from other, human-driven user accounts. This is an issue of democracy and security, and research that maps and addresses issues related to bots is important and much needed. However, definitions of bots vary notoriously. What constitutes a bot is far from a fixed or universal concept which is broadly agreed upon. For example, different expert communities, ranging from scholars in fields such as computational social science to developers in tech industries, use different definitions and varying criteria, to classify and discuss bots.

Today, the playing field around automated opinion-making and computational propaganda is changing rapidly with the swift emergence of artificial intelligence tools that produce human-like language, and which make it increasingly harder to distinguish between bot-operated and human-operated accounts (Guglielmi, 2020; Monaco and Woolley, 2022). As content produced through AI generation has become increasingly difficult to distinguish from content created in and through human communication (Torusdağ, Kutlu, & Selcuk, 2021), the question of what constitutes a bot, and also how it should be identified, has become all the more complex. In academic and technological discourse, definitions of bots can range from instances of very straightforward rule-based automation, to extremely sophisticated AI-driven agents that can also be capable of dynamic interaction. This conceptual ambiguity around bots has an impact both on research approaches and technical implementations.

Because of these developments, the classification of bots has become an urgent challenge in a wide range of areas, for example, content moderation on online platforms (Binns et al., 2017; Ravazzi et al., 2022), political prognostication (Boichak et al., 2018; Brachten et al., 2017; Cantini et al., 2022), mitigating misinformation (Himelein-Wachowiak, et al., 2021; Lanius et al., 2021; Zhen et al., 2023), and preventing dangerous real-world consequences (Schuchard et al., 2019). However, the ways in which bots are defined or classified vary depending on different disciplinary perspectives, as well as different institutional priorities. For example, while tech developers quite often define bots based on functional and operational criteria, scholars in the humanities and social sciences will be more likely to approach bots as sociotechnical constructs that are, in turn, seen as embedded in broader socio-political dynamics. The fact that such divergent framings co-exist influences the way bots are studied, and also the broader societal discourses on automation and agency.

The aim of this article is to analyse how different epistemic communities formulate and apply definitions of bots and to critically examine how these definitions align with disciplinary assumptions, methodological choices, and broader societal concerns. We use computational methods to analyse how bots are conceptualized in expert discourse, drawing on scholarly publications (Scopus) and developer discussions (Stack Overflow). The study uses keyword-in-context (KWIC) analysis to analyse how bot definitions are articulated in context, and topic modelling to identify and compare dominant discursive themes across the different domains, revealing both points of overlap and divergence. By identifying key patterns in expert discourse, the study highlights the epistemic boundaries that shape understandings of botness. Ultimately, the article contributes to a critical discussion on how definitional differences influence research agendas, technological implementations, and broader debates on automation, agency, and politics.

## BACKGROUND AND CONCEPTUAL FRAMEWORK

Social bots are a form of automation software that, through algorithms, are designed to mimic and potentially manipulate human behaviours (Keller & Klinger, 2019; Ferrara et al., 2019). In the social sciences and humanities, the existing scholarship on bots has a strong emphasis on socio-political consequences of the presence of bots in online discourse. Others have analysed which roles bots take up in online social networks (Seering et al., 2018). Such research is emphasising how bots are assigned different roles depending on the context in which they operate, and scholars have categorised bots as amplifiers, facilitators, gatekeepers, or disruptors, reflecting broader theoretical debates about automation, agency, and control in digital networks (Gorwa and Guilbeault, 2020; Fernqvist et al., 2018; Bulat and Hilbert, 2024; Doshi et al., 2024: Olanipekun, 2025).

In social science research, and more specifically also in the area of Critical AI Studies (Gorwa and Guilbeault, 2018; Woolley and Howard, 2018), bots tend to be framed as sociotechnical entities that are not merely technological artifacts, but which are entangled with, and influence, discourse and information ecosystems more broadly. This perspective highlights bots not only as source code or applications but as objects that are surrounded by political and epistemic – in other words, discursive – struggles. Bots can become a kind of 'empty signifier' (Wrangel, 2015) or 'nodal point' (Laclau & Mouffe, 1985) in relation to which different actors contest their meanings and roles in the digital society.

When interacting with users in social media feeds, it is seldom easy, and sometimes impossible, for both researchers and everyday users to assess if they are interacting with a human or not (Boshmaf et al., 2011; Ferrara et al., 2016; Howard, Kollanyi., and Woolley, 2016; Freitas et al., 2016). Further research has shown there is a political bot bias in the perception of online discourse (Schweitzer, Dobson and Waytz, 2024). This ambiguity may certainly be a challenge for everyday users of digital platforms and systems, but also for experts, as scholarly and technical communities may define bots in different ways. Some definitions, for example, may focus on functional elements such as automation or interactivity (Howard and Kollanyi, 2016), while others incorporate broader socio-technical definitions where bots are seen as embedded in human networks (Gorwa and Guilbeault, 2020). Additionally, as developments in generative AI continue, the boundary between automated and human-driven behaviour becomes increasingly blurred which, in turn, makes it more difficult to establish clear conceptual distinctions between different types of entities that are interacting online (Olanipekun, 2025).

Indeed, today the study of bots has become a research field in its own right (Subrahmanian et al., 2016; Gorwa and Guilbeault, 2020; Martini et al. 2021; Monaco and Woolley, 2022). However, as this type of research has expanded, it has also fragmented into different disciplines. Technical and computational research largely frames bots as software or algorithmic systems that can be optimised, detected, or mitigated (Aljabri et al., 2023; De Morais & Digiamp, 2021; Dialektakis et al., 2022; Torusdağ, 2022). On the other hand, scholars in the humanities and social sciences are to a much higher degree approaching bots as social, cultural, and political entities in analyses of, for example, issues of disinformation and manipulation (Woolley and Howard, 2018). Such diverging perspectives, especially when they are taken up in parallel in people's broader understandings of bots, may contribute to definitions of bots remaining field-specific rather than generic as they are shaped by different theoretical

or epistemological assumptions or methodological priorities. This, in turn, can give rise to conceptual inconsistencies, where one and the same term – 'bot' – refers to fundamentally different entities depending on in which context it is discussed. This conceptual instability can, among other things, raise methodological concerns as studies that rely on different definitions may produce findings that are not directly comparable, which can further limit interdisciplinary dialogue.

Consequences of the instability of definitions of bots are particularly evident in the domain of bot detection, where the lack of clear definitional boundaries has long been a challenge. Two primary dilemmas are recurring in the literature for current bot detection methods: the ground-truth problem, which refers to the validity of results, and the impossibility of replication (Martini et al. 2021). The ground-truth problem refers to the uncertainty of the number of fully or partially automated accounts in the total population or a sample A, which can be compared to a manually or automatically coded sample B to validate the detection tool results. There is no ground-truth data available or attainable replication (Martini et al. 2021), and any detection method can only estimate automation by identifying accounts with similar or diverging patterns from typical human behaviour. The second challenge concerns replicability. Data quickly become outdated due to the constantly changing nature of social media. Accounts may be deleted, or their owners may remove followers or content, causing changes in displayed behaviour and network properties. Detection tools also evolve, so results achieved through newer versions are incomparable to older versions, making analyses time-sensitive and leading to different results if replication is attempted.

Considering the ground-truth problem and the impossibility of replication, results remain uncertain, making it difficult for researchers to confidently determine the number of automated accounts within a given sample. Different detection methods will yield different results, and specific methods may even generate varying outcomes when used at different points in time (Rauchfleisch & Kaiser, 2020). Studies have also shown that, with current techniques, threshold bot scores - even when applied conservatively – are subject to variance, resulting in false negatives (i.e., bots being classified as humans) and false positives (i.e., humans being classified as bots) (Rauchfleisch & Kaiser, 2020; Schuchard & Crooks, 2021; Martini et al., 2021).

On the one hand, the differing definitions discussed above can be argued to simply reflect natural, necessary, and expected variations across fields. Certainly, different definitions may be needed for specific purposes, such as developing field-specific methods, or devising strategies or tools to meet unique demands and challenges within different fields. On the other hand, however, the differences can also be seen as reflective of deeper epistemic divides. Problems may arise if the different origins or underlying assumptions of these definitions are not acknowledged or critically examined. It is against this background that this article examines how bots are conceptualised in scholarly and technical discourse. The analysis of both academic literature (via Scopus) and developer discussions (on Stack Overflow) maps different definitions, and further problematises what epistemic assumptions may underlie such differences. Importantly, rather than arguing for any single universal definition, the goal is to critically map discursive variations in order to identify points of convergence, divergence, or potential misalignment across domains and disciplines.

In terms of its broader conceptual framing, this article positions itself in the emerging research field of Critical AI Studies (Lindgren, 2023; Roberge & Castelle, 2021). The study,

through its discursive perspective, approaches bots not as fixed technological artifacts, but rather as concepts that are shaped by different epistemic communities. Broadly speaking, we approach bots from the theoretical perspective of the social shaping of technology (Pinch & Bijker, 1984; Williams & Edge, 1996). Definitions of bots are not merely technical classifications but sociotechnical constructs. Differing framings in different contexts can be seen as illustrations of how technological and social dimensions of bots are co-produced rather than existing in opposition. Bots are socially shaped and are co-produced at the intersection of the social and the technical (Lindgren, 2023). The question then, is not simply what bots do, but how different expert communities discursively construct their meaning, where we can see an agent's 'botness' as a fluid and contested category which can, in turn, be shaped by broader discourses about agency, authenticity, manipulation, and so on. The definitions used in any given case is reflective of deeper assumptions about what should be seen as analytically meaningful when studying bots.

For example, relying on a purely metrics-based approach when defining bots – such as posting frequency, time of activity, account creation dates, or follower counts (Kearney, 2018; Yang et al., 2020) – entails a reduction of the bot to a computational artifact. In contrast to that approach, it has been argued that the understanding of a bot must instead be 'connected to its use, and its social and cultural contexts' (Coeckelbergh, 2022, p.9). Thus, from a sociotechnical perspective, bots are more likely to be understood in terms of their relational, performative, and context-dependent characteristics rather than based on their merely technical attributes. While the metrics-oriented approach captures a straightforward kind of botness – 'the likelihood of being a bot' (Rizoiu et al., 2018, p. 300), or 'the level of bot-like activity' (Hui et al., 2019, p. 3) – there are also more far-reaching forms of botness. Bucher (2014), for example, sees botness as a more fluid and deeper-running property which has to do with the 'personality' of bots. This view clearly aligns better with the sociotechnical perspective, as it also highlights the 'doing of botness' (Bucher, 2014, p. 11) as a constructive process of meaning-making.

This study, rather than viewing botness as a static property, draws on the concept of digitally transformative processes (Lindgren, 2022) in its analysis of how definitions of bots differ and evolve across expert communities. Again, the meaning of 'bot' is not fixed but shifts as technologies change, and importantly also as different fields apply new conceptual frameworks. Such transformations reflect what Earl and Kimport (2011) describe as 'model changes,' where not only the superficial classification criteria but the fundamental understanding of what constitutes a bot, is altered. By mapping these definitional shifts, this article gives knowledge about tensions between competing perspectives and how they might contribute to shaping broader discussions on automation, agency, and technological governance.

## DATA AND METHOD

As introduced above, the data used in this study consists of expert discourse on bots within two distinct domains: (1) scholarly research articles from the Scopus database, and (2) technical discussions from Stack Overflow, a widely used discussion forum for developers. The data collected from Scopus will give knowledge about how bots are discursively framed within academic literature, while the data from Stack Overflow will give insight into discourse on

practical and technical aspects of bots, related to coding practices and real-world applications as discussed in a more applied context. Bringing textual data from these two domains together helps us get a comprehensive understanding of how bots are discussed and defined across different expert contexts, where the simultaneous focus on theory and practice will help us identify common themes, as well as divergences, in how bots are seen and used. First, a dataset was collected from Scopus by using the following search string:

```
TITLE ( "bot" OR "bots" ) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (
LIMIT-TO ( SUBJAREA , "COMP" ) OR LIMIT-TO ( SUBJAREA , "SOCI" )) AND (
LIMIT-TO ( DOCTYPE , "cp" ) OR LIMIT-TO ( DOCTYPE , "ar" ) ) AND (
LIMIT-TO ( LANGUAGE , "English" ) )
```

This, in plain language, means that the Scopus data was collected by targeting scholarly publications that are explicitly engaging with the concept of bots by sampling only articles where the title (TITLE) contained either "bot" or "bots". This was to ensure a certain level of relevance to discourse directly centred around the term. Furthermore, to keep a focus on contemporary discourse only items with their publication year (PUBYEAR) falling within the time period of 2014 to 2024 were included. The selection was also refined by limiting the dataset to the two subject areas (SUBJAREA) of Computer Science (COMP) and Social Sciences (SOCI). The aim of this filtering was to ensure a certain degree of balance between technical perspectives, such as those relating to AI and automation, and social perspectives that may engage more with bots in relation to societal roles, interactions and cultural meanings. Additionally, we applied a further limitation to focus only on the two document types (DOCTYPE) of journal articles and conference papers. Finally, only English-language publications were included, both to ensure consistency in the computational text analysis to follow, as well as to enable comparisons with the Stack Overflow dataset, which is purely in English.

The full-text articles were downloaded and converted from pdf format to plain text (VikParuchuri, 2025) and then converted to lowercase. We tackled the methodological challenge of finding definitions of "bot" in these full-text sources by using a rule-based approach in combination with regular expressions (RegEx), which is a powerful tool for pattern matching in text (Thompson, 1968). We used a range of linguistic patterns commonly found in definitional statements, including “bot is,” “bots are,” “bot(s) mean(s),” “bot(s) function(s),” “bot(s) operate(s),” “bot(s) can,” “bot(s) will, and “bot(s) refer(s) to.” Note that these will by extension capture wordings such as "bot are defined as", "a bot can be said to", and so on. We also used phrasings referring to negations of bots, such as "bot(s) can't/cannot", "bot(s) isn't/is not (aren't/are not)" and "bot(s) don't/do not". The RegEx used to identify definitional statements was:[1]

```
\b(bot|bots)\s+(is|are|means?|functions?|operates?|can|will|refers?|can
not|can't|isn't|is not|aren't|are not|don't|do not)\b
```

As mentioned above, aside from these scholarly texts our data also included a subset collected from Stack Overflow (https://stackoverflow.com), which is a popular online community where developers and programmers ask and answer questions related to coding and

software development (Barua et al., 2014). Full data from Stack Overflow is made publicly available through Google BigQuery, a cloud-based platform for analysing large datasets. (Fernandes & Bernardino, 2015). We ran an SQL query to extract posts from 2014-2024 across all of Stack Overflow, that matched either "bot" or "bots" (n=71,202) and then extracted definitional statements using the same RegEx as above. As shown in Table 1, the full dataset of bot definitions ended up having a size of 20,264 phrases.

**Table 1.** Number of retrieved documents and definition phrases across sources

| Source | Timeframe | Articles/posts | Definition phrases Number (Phrases/document) |
|---|---|---|---|
| Scopus – social science | 2014-2024 | 493 | 2,153 (4.3) |
| Scopus – computer science | 2014-2024 | 1922 | 3,424 (1.8) |
| Stack Overflow | 2014-2024 | 71,202 | 14,687 (0.21) |
| | | | **20,264** |

## KWIC Analysis

When analysing the data, we first did a concordance analysis. This approach, often used in the field of corpus linguistics, allows for looking at in which contexts, within a body of text, specific words or phrases are used. For the purpose of our analysis, we created a KWIC (Key Word in Context) concordance – an analysis where the "word-form under examination appears in the centre of each line" (Sinclair, 1991:33). This analytical step, carried out using the NLTK (Natural Language Toolkit) programming library (Bird et al., 2009), enabled us to see the specific textual context in which the word forms 'bot' and 'bots' occurred in our datasets. This, in turn, makes it possible to pick up on patterns of usage that might not be apparent through other types of analyses. The KWIC concordance, functioning as a first foundational step of our analysis, is also a form of collocation analysis (Chung, 2017) in the sense that it identifies words or phrases that appear often around our target words of 'bot' and 'bots', thereby giving an insight into the types of definition that this article analyses.

## Topic Modelling

Crucially, the KWIC mapping and analysis of definitions, while interesting in itself, also serves as the basis for moving on to a more refined computational analysis of more complex discursive patterns across all three discursive communities. In this step, we apply topic modelling to the full combined dataset to try to identify recurring themes, discursive overlaps, as well as points of divergence when it comes to how bots are framed across the different contexts. The point with this part of the analysis is to enable us to also move beyond the isolated domain-specific discourses analysed through KWIC, with the goal of tracing more complex discursive structures that shape expert discourses on bots. For example, this analytical strategy makes it possible to see if certain discursive patterns consistently exist across all three domains, and which distinct boundaries seem to persist.

For the topic modelling, we continued to rely on the concordance data that was extracted through the KWIC analysis, rather than using the entire full-text documents. Not including the full academic articles and discussion posts, but instead treating each KWIC context window as

a separate document, ensured that the topic modelling focused specifically on how bots are defined and framed. In practice, then, this means that each document in the topic modelling corpus consisted of a short segment of text surrounding the term "bot" or "bots" drawn from one of the three datasets. The document set for the topic modelling thus matches the 'Definition phrases' column in Table 1, with a total of 20,264 documents.

Our topic model was trained using LDA (Blei 2003), which identifies topics in a text dataset by assigning words to topics based on their co-occurrence patterns. The training was done using the Gensim library for Python (Řehůřek & Sojka 2011), which provides a user-friendly implementation of the algorithm. When it came to choosing the number of topics to model – as LDA does not automatically determine the optimal number – we used a so-called elbow method based on coherence scores to guide our decision.

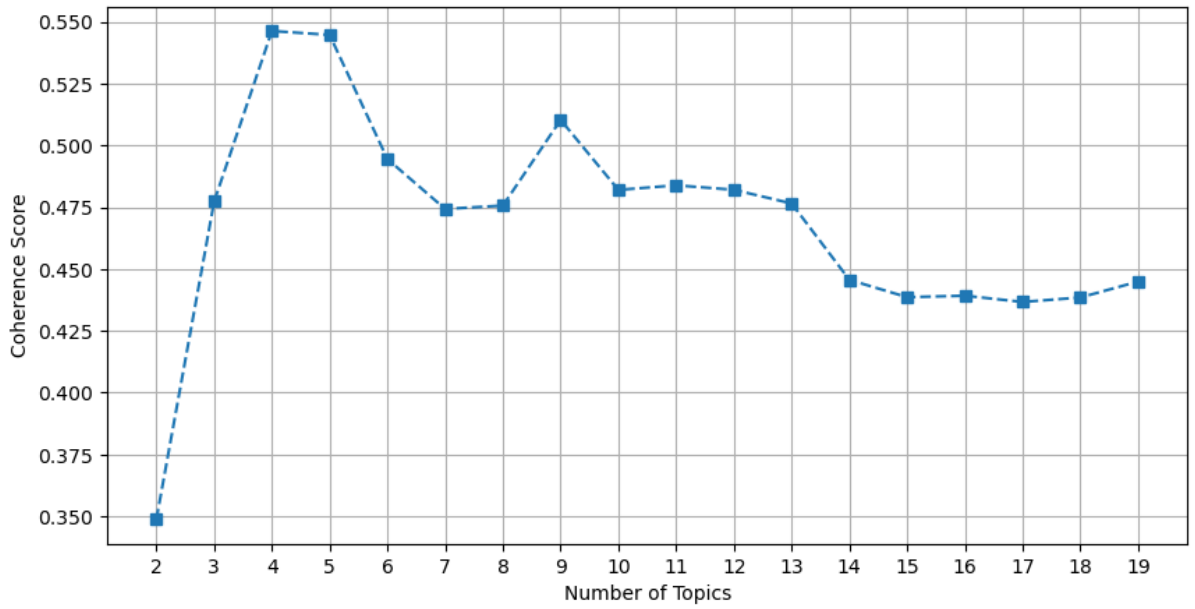


**Figure 1.** Coherence scores vs. number of topics (LDA model)

While training the model for 4-5 topics gives the highest coherence score, we chose to train the model for 9 topics, as using a too low number of topics is likely to merge thematic clusters that can be analytically meaningful. So, choosing to train the model for 9 topics is likely to strike a better balance between the coherence score of the model and the granularity and interpretability of the topics. The topics produced were manually labelled after qualitative assessment of key words associated with them and then plotted using the pyLDAvis tool (Mabey, 2018) to enable an analysis of the distribution of topics across the three discursive domains—computer science, developer discussions, and social science.

## ANALYSIS

In the following sections, we first present the KWIC analysis of variations in how bots are defined in order to examine some broader discursive patterns around bots in the three analysed domains. After that, we use topic modelling to identify dominant discursive themes across the domains, and to further analyse how these themes cluster in relation to each another. This enables a mapping of the epistemic boundaries that shape bot discourse, highlighting both areas of overlap and points of divergence.

### Computer Science: Bots as functional and technical entities

After carrying out the KWIC analysis, as described earlier, we made a qualitative assessment by manually reading through the concordance lists created based on each part of the dataset. First, we looked closer at how 'bot' and 'bots' were defined and described in the subcorpus from the computer science domain on Scopus. Table 2 lists 20 manually selected illustrative examples that are characteristic of this part of the discourse.

**Table 2.** Computer science definitions of bots: qualitative selection of 20 KWIC examples

| Left Context | KWIC | Right Context |
|---|---|---|
| terances 2 related work conversational bots | bots | are computer programs that provide natural l |
| media on the social media landscape social | bots | are defined as automated accounts designed t |
| lassification received march 17 2022 social | bots | are defined as computer algorithms that gene |
| thout being disclosed as pieces of software | bots | are defined as software designed to act in w |
| 0 repositories in microsoft these developer | bots | are deployed in continuous delivery environm |
| with specific service platforms as a result | bots | are designed and optimized for these specifi |
| d at a faster rate ii related work the chat | bots | are developed by training the system based o |
| s we saw in the previous subsections sniper | bots | are developed to perform buy operations imme |
| s and needs in a more natural way while the | bot | can accurately understand and give an approp |
| ed work storey and zagalsky 11 propose that | bots | can act as conduits between users and servic |
| opinion spam messages or amplify propaganda | bots | can act as fake accounts eg for posting mess |
| signed for benign purposes for example chat | bots | can assist retailers in serving customers in |
| a multivocal literature review furthermore | bots | can help developers complete tasks related t |
| ption as well as potential ways that future | bots | can support different groups of moderators i |
| ial bots as per ferrara et al 2016 a social | bot | is a computer algorithm that automatically p |
| oaxes alternate narratives 1 introduction a | bot | is a computer application that is designed t |
| e game items in an economical manner a game | bot | is a computer program that plays games auton |
| ne of the most prominent today are bots 1 a | bot | is a computer program that simulates human a |
| ds for the users due to the bots high power | bots | will vote for posts even if other users do n |

The examples are all indicative of the general patterns found when going through the concordance list. A general pattern here is that the computer science discourse on bots primarily defines them as automated software agents with a wide range of applications and uses in areas like social media automation, cybersecurity, and e-commerce. In terms of definitions, this part of the discourse certainly reflects the type of fluidity and ambiguity discussed in earlier parts of this article. However, and importantly, the fluidity hinted at in the computer science domain

is more about the fact that there may be many different types of bots, rather than a more existential one. For example, ambiguity seems to exist when it comes to distinguishing between fully automated, semi-automated, and more human-controlled bot systems. This may, for example, be about moderation bots or trading bots that rely on human input to function in the intended way, or customer service bots that pass the more complex queries on to human operators.

Furthermore, in the computer science literature, bots are often defined in terms of whether they are benign or malicious, where benign bots tend to be associated with notions of efficient automation and productivity enhancements, while malicious bots are discursively linked to cyber threats, fraud, disinformation and political manipulation. In other words, different types of functional definitions are prominent in computer science definitions of bots. Such ways of approaching bots can be seen as reflecting a pragmatic engineering perspective, where bots tend to be defined simply by what they do, rather than on any pondering or reflection around any underlying nature or other, more philosophical or ontological considerations.

While this focus may be understandable and expected within its specific disciplinary context, there is still a risk in operating with definitions that are too strongly oriented towards pragmatism, neutrality, and problem-solving. Definitions that are overly functional may contribute to obscuring broader social and political stakes that may be involved in processes where bots are developed and deployed. Indeed, if one treats bots primarily as technical things and not as socially embedded entities, important concerns around, for example, accountability or any unintended consequences may be sidelined. So, by mapping out how bots tend to be defined in computer science, we can get some insight into what implicit assumptions may shape their technological development. From a discourse analysis perspective, definitions are not merely descriptive, but they actively contribute to shaping the social practices where we build, deploy, and govern bots.

## Stack Overflow: Bots as practical implementations

Moving on with the KWIC analysis, we now turn to an analysis of how 'bot' and 'bots' are defined in the strongly developer-oriented discourse on Stack Overflow. This list consisted of 14,687 lines, with the discussion forum text excerpts being significantly messier and less structured than the scholarly articles. However, the strategy of sorting the list alphabetically on the word following after the KWIC was particularly helpful here as it enabled a more efficient qualitative scanning of the context in which 'bot' and 'bots' were appearing. Table 3 shows 20 illustrative examples of definitions and discursive context.

**Table 3.** Developer definitions of bots: qualitative selection of 20 KWIC examples

| Left Context | KWIC | Right Context |
|---|---|---|
| .on whenever i test my form it works but the | bots | are finding a way to bypass the script i hav |
| .ng to solve this issue for quite awhile now | bots | are hitting my sites hard with invalid host |
| charlies ip 100038080 all of these | bots | are living in containers behind a nginx prox |
| very odd problem the problem is both of the | bot | are responding to postbacks button instantly |
| ongyes i did itstrong what amaze me is that | bots | are scanning github for searching free api k |
| ep pin this real life microsoft example the | bot | automatically comes up with a message and th |
| one transfer originurl styleurl codepre now | bot | can answer multiple requests but when it tea |
| tep pi know this would not be perfect and a | bot | can download the page and simulate the click |
| ein progress and in which form so the teams | bot | can edit and overwrite the status is it poss |
| to bot but there is nothing available where | bot | can extract contents of pdf sent by user wil |
| base to the twilio autopilot bot so that my | bot | can fetch data from the database and show it |
| .ng we want to be able to subscribetotone so | bot | can provide appropriate help during the meet |
| s right away when they are released so this | bot | can purchase your desired items in an instan |
| the code for specific keywords so that the | bot | can respond accordingly and no i can not use |
| lithe prefix is saved in a config file the | bot | can write to the file and save it for later |
| python botpycode since py only denotes that | bot | is a python file i assumed this because when |
| your server implementing a code where that | bot | is able to be used as a normal useraccount a |
| otyour message contained a linkquot but the | bot | is not working i have tried a lot of differe |
| self with the administrators permission the | bot | will recognize and punish the memberstrongp |
| eated and deployed a bot in microsoft teams | bot | works properly and responds when user talks |

In comparison with the discourse of the computer science research literature, the discourse on Stack Overflow – dominated by programmers and developers – is even more pragmatic and focused on immediate problem-solving. This means that, while computer science definitions are largely engaged in functional definitions and classifications, the developer discussions are, unsurprisingly, not at all offering any explicit definitions of bots, but instead describe bots indirectly through their design, implementation, constraints, and behaviours in response to different commands. This, then, puts the focus on similarly functional definitions as in the computer science discourse, but largely also on activity-oriented definitions. This is because in the Stack Overflow subcorpus, bots are primarily defined in terms of tasks that they execute – particularly in relation to messaging, API interactions, and task automation – such as by 'finding', 'responding', 'scanning', 'downloading', 'purchasing', 'recognising', and so on (cf. Table 3). In spite of the overlaps, a difference between the computer science discourse and the discourse on Stack Overflow is that the former still largely defines bots as autonomous agents, while the latter tends to frame them as extensions of user commands, objects to shape and get to function, rather than as independent entities.

This focus on direct functionality and execution highlights a key distinction: while both domains analysed this far are centering on what bots *do*, the developer discourse places even less emphasis on conceptual clarity or categorisation. This is not to say that these discursive fields should be expected to, or required to, engage deeply in theoretical discussions around defining bots. Nonetheless, the analysis thus far of the first two cases illustrates how disciplinary and professional priorities tied to different domains shape how bots are discursively understood. Each domain is, more or less implicitly, embedding its own specific

assumptions of what a bot is and does into its language and practice. After having analysed the two more technical and applied domains, we turn not to the final part of the KWIC analysis focusing on how bots are defined in the social sciences.

## Social Science: Bots as socio-technical and contested constructs

The third and final part of the KWIC analysis is focused on how 'bot' and 'bots' are defined and discussed in social science discourse. In comparison with the two previously analysed cases, this one reflects a quite different epistemic orientation that is much more focused on contextual meaning. Table 4 shows 20 qualitatively chosen examples that illustrate broader patterns in this discourse. It should be stressed here, again, that while these differences align clearly with expectations and activities in the domains analysed, the mapping carried out through KWIC will form the basis for a more refined computational analysis of bot definitions across all three discursive communities through topic modelling.

**Table 4.** Social science definitions of bots: qualitative selection of 20 KWIC examples

| Left Context | KWIC | Right Context |
|---|---|---|
| ound and literature review terminologically | bots | are a dazzling phenomenon and describe a bro |
| n fig 3b it turns out that most noncredible | bots | are also parasitic on rightleaning celebrity |
| parkland events we can conclude that social | bots | are an explicit subpopulation of actors in o |
| l reasoning myside bias introduction social | bots | are artificial agents that infiltrate social |
| ns underexplored whether manipulated social | bots | are as active as humans in climate change di |
| ed humans more frequently then conservative | bots | are better at being perceived as humans poli |
| mation flows more than just tools wikipedia | bots | are both sociotechnical agents engaging with |
| rch projects have made it clear that social | bots | are by no means a merely technical phenomeno |
| ing across different languages in wikipedia | bots | are governed differently in different langua |
| hear any different voices especially if the | bots | are highly skilled at disguising themselves |
| amic interactions in sociotechnical systems | bots | are imbued with technical agency and a uniqu |
| our study and the egbf study is that for us | bots | are inextricably linked to their developers |
| sanction asian issues in many topics social | bots | are not significantly different from humans |
| working in the it industry highlighted how | bots | can manipulate public opinion by disseminati |
| nes wrote the question is no longer whether | bots | can pass as human but how social interaction |
| 20 as budnikova os babenkova note that chat | bots | can radically change the nature of human int |
| bots in journalism the definition of social | bots | is contested and varies among research field |
| hen et al 2008 describe this as the ratio a | bot | is mistaken for a human player this is |
| tives but how the expressive power of these | bots | is symbiotic with the fact their outputs pro |
| discovered the behavior patterns of social | bots | will change constantly in the future and thi |

When analysing the third part of the data, covering social science discourse on bots, we found an orientation that was clearly different from that of the two others. While, in the previous domains, bots were predominantly framed in terms of either their functionality or their technical properties, the social science discourse to a much larger extent defines bots as parts of broader sociotechnical systems. One of the most central themes in these texts is the idea that bots are not to be seen as merely neutral tools or simply automated agents, but instead as entities the meaning, impact, and role of which are shaped by their interactions with human intentions,

institutional structures, and political contexts. This discursive theme is, for example, evident in relation to those definitions that link bots to political influence and to the manipulation of public opinion (e.g., "bots can manipulate public opinion by disseminating a large number of messages"), as well as in statements that emphasise their entanglement with human agency (e.g., "bots are inextricably linked to their developers rather than autonomous agents").

A recurring feature in this discourse is the explicit contestation of bot definitions. Rather than assuming a clear-cut functional classification, social science texts tend to problematize what a bot is and how it is perceived. This is particularly visible in the statement "the definition of social bots is contested and varies among research fields", which highlights the interdisciplinary tensions around conceptualizing bots. Similarly, the notion that "bots are by no means a merely technical phenomenon but change sociotechnical systems" reinforces the idea that bot classification cannot be disentangled from their broader social and cultural implications.

Another clear contrast to the other two domains is the emphasis her on the ambiguity of bot identification. A significant number of examples are highlighting how bots blur the boundaries between automated agency and human agency. There are for example wordings such as "bots are a dazzling phenomenon and describe a broad array of applications", and "bots are not significantly different from humans, however, from the social science perspective, they […]". Overall, then, there is a recurring concern in social science discourse with the misrecognition of bots, and that bots can be strategically disguised in online interactions. Indeed, as discussed above, concerns relating to deception, disinformation, and strategic uses of bots are not entirely unique to social science discourse, as such themes also appear in the computer science literature. This is especially true in relation to discussions of malicious bots. A key difference, still, is that these issues are framed in quite different ways in the two domains. In computer science discourse, these aspects tend to be approached through a more functional lens (detection, classification, mitigation), while in social science discourse the very process of defining bots is construed as inherently problematic, and deeply shaped by sociotechnical entanglement and broader power dynamics. Furthermore, in the social science discourse, there is often an emphasis on the fluid and evolving nature of bots (e.g., "bots will change constantly in the future and this evolution will […]". This focus on transformation and instability stands in contrast to the, by comparison, relatively stable functional and practical definitions in the technical fields.

In sum, then, the KWIC analysis of all three domains highlights one fundamental discursive contrast when it comes to the definition and understanding of bots across the areas. While computer science and developer communities primarily define bots in terms of technical properties, functionalities, and immediate implementations, social science discourse to a larger extent problematises such definitions. It does this by emphasising the sociotechnical entanglements that shape how bots are understood. This difference can be seen as reflecting a broader concern with the ways in which technology is embedded in political, institutional, and cultural contexts. Overall, the KWIC analysis shows how definitions of bots are not neutral descriptions that are universal across fields, but that they rather are a form of discursive markers that reflect and shape which aspects or interpretations of bots are prioritised in different settings. While such differences may seem unproblematic from a directly practical point of view – of course, a developer will have a more practical focus than a sociologist – they still become significant in relation to things such as interdisciplinary dialogues or policy

discussions. In such settings, competing assumptions about what a bot *is* and *does* can lead to misalignments in theoretical debates, and methodological strategies, as well as have broader societal implications. Now, to investigate this pattern further and to try to identify discursive patterns across domains, we turn to topic modelling as a complementary approach to map the terrain of bot discourse.

## Beyond Discursive Boundaries: Topic modelling across domains

Now moving on to the analysis of overall discursive patterns in bot definitions across all three domains, we will use the trained LDA model to assess how topics are distributed across them. First, we shall have a look at which topics were identified and how they can be related to the patterns found in the KWIC analysis.

Table 5 shows top keywords in the nine identified topics in the full dataset, including the definition phrases from all three domains. These topics have then been qualitatively labelled based on their thematic content.

**Table 5.** Identified topics in bot definitions across domains

| Topic # | Keywords | Label |
|---|---|---|
| 0 | trying, command, error, reply, execute, fail | **Execution and errors in bot commands** |
| 1 | social, political, news, account, network, influence | **Bots and sociopolitical influence** |
| 2 | interact, task, game, player, automation, control | **Bots in interactive and automated systems** |
| 3 | message, send, user, server, request, response | **Messaging and communication bots** |
| 4 | function, run, process, framework, implement, system | **Bot functionality and system implementation** |
| 5 | role, response, user, message, engagement, moderation | **Bots in moderation and user engagement** |
| 6 | human, activity, interaction, behaviour, perception, agency | **Human-bot interaction and agency** |
| 7 | const, codepre, def, await, script, method | **Bot programming** |
| 8 | wikipedia, account, edit, rule, governance, verification | **Bots in knowledge management and governance** |

When it comes to the distribution of topics across the three domains – computer science, social science, and developer discourse – Figure 2 indicates that there is some variation in the concentration of topics within each domain. The numbers in the heatmap state the proportion of documents within a given domain for which the topic in question was the dominant one, where a darker shade means a high prevalence. For example, the topic *Political and social* is particularly dominant in the social science discourse (0.48), but also in the computer science discourse (0.42), but nearly totally invisible in the developer discourse (0.01). As a contrast, *Messaging and communication* is very much present in developer discourse (0.47), but much less so in the two other ones. Furthermore, the figure shows that some topics (for example, *Human-bot interaction* and *Functionality and implementation*) are more evenly distributed across the discursive domains, suggesting that they are more relevant to all of them.

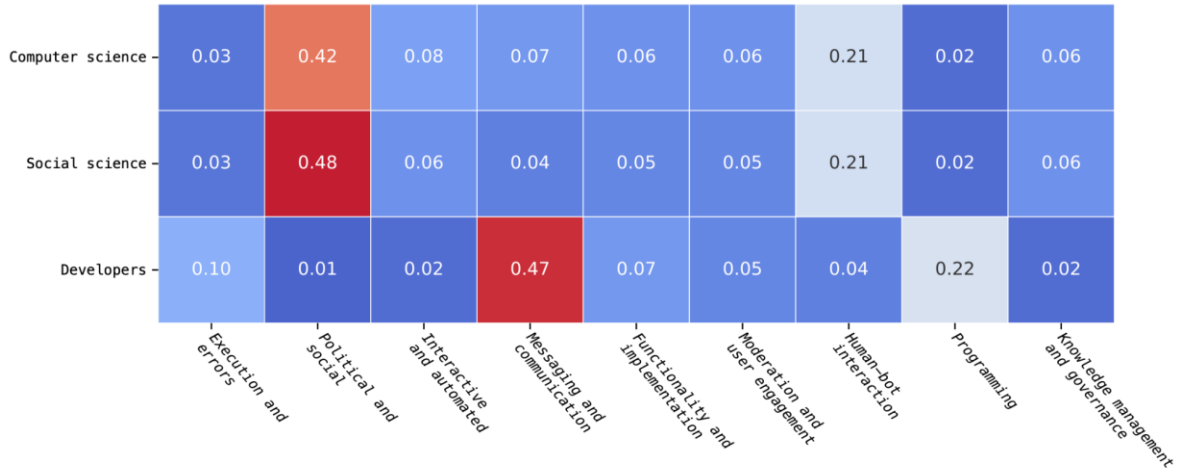


**Figure 2.** Distributions of topics in bot discourse across domains

Figure 3 shows the mapping, done with pyLDAvis, of the positions of topics in a two-dimensional space based on their relationships and similarities. The axis names PC1 and PC2 simply refer to "Principal Component 1" (dimension 1) and "Principal Component 2" (dimension 2) resulting from the reduction of the multidimensional LDA model to 2D, implemented in pyLDAvis. The interpretation of the map should thus focus on how the topics are positioned relative to each other rather than on their absolute positions on the plot. The main task of the plot is simply to give a picture of the overall structure and distribution of topics within the dataset, highlighting how closely or distantly related they are to one another. The sizes of the circles in the plot represent the relative prevalence of each topic. In other words, a larger circle indicates that a topic appears more frequently across the documents, which can be interpreted in terms of them being more dominant in shaping the overall discourse on bots.

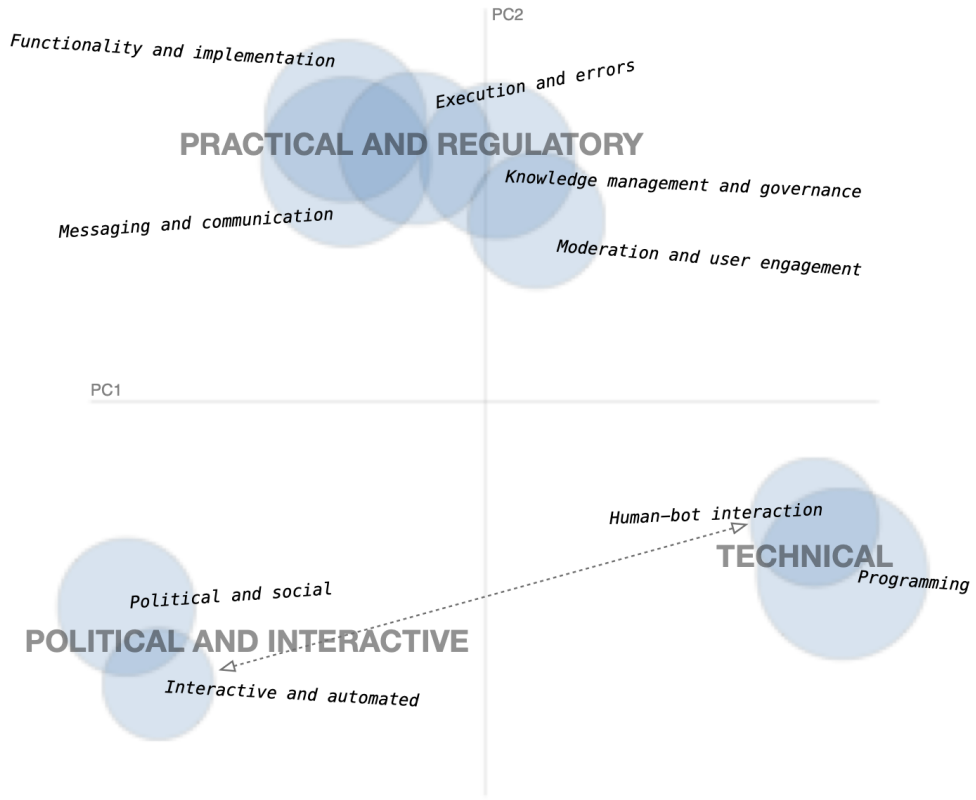


**Figure 3.** Spatial relationships among identified topics

Looking first at clusters and proximity, one of the most significant findings in the plot relates to the largest group of topics where f*unctionality and implementation*; *execution and errors*; *knowledge management and governance*; *messaging and communication*; and, *moderation and user engagement* appear close together. This means that these aspects of bot discourse and bot definitions are tightly interlinked and that they can be said to form a core discursive space where discussions around technical implementation, governance, and moderation frequently intersect with each other. Overall, then, this cluster highlights that technical and social aspects can appear together when speaking of bots.

However, only some dimensions of 'the social' seem to be addressed. For example, issues of moderation, messaging, and governance are integrated here, while broader sociopolitical concerns are absent. The main discursive space does not extend naturally to more critical debates such as those found in the cluster on *political and social* dimensions. Instead (see, the lower left corner of Figure 3), these appear to form part of a more distant and separate cluster. Together with the topic on *interactive and automated* aspects of bots, this cluster suggests that there is a more far-reaching rift in bot-related discourse between the practical and regulatory aspects in one space and the political and interactive in another. Furthermore, in the lower right corner of the plot is an overlapping cluster of *human-bot interaction* and *programming*, indicating that the programming topic, likely largely driven by the Stack Overflow dataset,

overlaps with many of the key terms in the *human-bot interaction* topic, but that this overlap still does not bridge into neither the more practical and regulatory discourse, nor to the socio-political one. The pattern that is the most difficult to interpret here relates to the positioning of the two topics on interaction (see the dotted arrow in the plot). The positioning of these topics could potentially reflect that the notion of interaction is ambiguous and operates at different levels of meaning across discourses.

## CONCLUSION

This article makes two key contributions, where the first one is purely empirical in the sense that it has shown, using KWIC analysis, both that bots are defined differently in different fields, and what these different definitions look like. This insight is expected in the sense that it confirms the likely hypothesis that experts in different areas will define bots based on conventions in their respective domains. The second contribution, made through topic modelling, is more novel as it concretely shows that, when bot definitions from different domains are analysed together, the definitional difference found clearly align with discursive silos that are unlikely to intersect. In other words, the mapping in Figure 3, reveals that bot discourse is not only shaped by domain-specific priorities (cf. KWIC analyses), but that it is also structurally separated into different conceptual clusters. The key difference here, simply put, is that while the KWIC analysis showed *what* the definitional differences look like between domains, the topic modelling and Figure 3 reveal *how* these differences are structured in relation to each other. The key conclusion then is that bot discourse is not only characterised by varying terminologies or different choices of focus but that it is fundamentally fragmented into separate and distinct epistemic spaces with minimal overlap.

This fragmentation has serious implications. First, it shows that while discussions of governance and regulation acknowledge both technical and social aspects, they still do so in a way that excludes any broader political and ideological perspectives. Second, it raises questions about whether policy and design frameworks have the vocabulary for fully taking the socio-political dimensions of bots into account. Finally, the isolation of programming discourse – even if possibly strengthened by the particular character of the selected dataset – can to some degree be said to imply that technical implementations of bots is in many cases treated as a neutral or apolitical process. Taken together, these findings highlight that there is a need for more integrative approaches in research and policy, both to bots in particular and to AI and automation more broadly. The discursive silos can limit interdisciplinary engagement in these areas, indicating that we need more integrative approaches to make sure that issues of automated agency in society are not just shaped within isolated domains but informed by a broad spectrum of perspectives and expertise.

## ENDNOTES

1. The regular expression \b(bot|bots)\b ensures that "bot" or "bots" are matched as whole words. The \s+ component guarantees that a space follows these terms. The parenthesis (…) groups various verb variations, covering definitional statements such as "is," "are," "means?," "functions?," "operates?," and "refers?," where s? allows for singular and plural forms (e.g., "means" or "mean"). It also includes descriptors of bots' capabilities like "can" and "will," as well as negations such as "cannot," "can't," "isn't," "is not," "aren't," "are not," "don't," and "do not." The \b word boundary, finally, prevents partial matches, ensuring, for instance, that "can" is detected correctly without also matching unrelated words like "candy."

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# EXPERIENCES OF LEARNING AND SUPPORT IN ONLINE COURSES IN OPEN UNIVERSITY STUDIES

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Abstract: *Studying online has increased in recent decades. In this study, we investigated 1) how adult students experience their learning through online courses, and 2) the support and guidance they receive in an online course? The data were collected through an electronic questionnaire with 182 respondents and analyzed qualitatively using thematic analysis. The findings highlight the importance of interaction with peers and instructors, which, according to the respondents, leads to a profound and broad understanding of the subject being studied. The findings also show that instructional and peer supports for online courses were felt to facilitate studying when easily accessible. However, some adult and experienced students felt that they did not need much instructional support and guidance or peer support. In the future, it will be important to take into account the diversity of the open university student population and their different needs.*

Keywords: *online learning, online course, higher education, student experiences, instructional support and guidance, interaction.*


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## INTRODUCTION

Online learning is a rapidly growing field of education worldwide because it provides flexible and convenient access to educational opportunities for students from diverse backgrounds and geographical areas who often cannot access higher education through other means (Farrell & Bruton, 2020; Roddy et al., 2017). The COVID-19 pandemic has further increased the number of online universities (Rivera-Vargas et al., 2021) and according to Stuart et al. (2022), online learning is now a core feature of the higher education system and will remain an enduring legacy of the COVID-19 pandemic. However, it is unlikely to replace traditional higher education, rather, it will serve as an alternative (Sun & Chen, 2016).

This study looks at online course experiences at the University of Jyväskylä, where adult students mainly study online. The reasons for studying can vary. Students enroll in individual courses or study units for personal interest, for further education, or eventually to apply for a degree program. Online learning offers flexibility to adult students, who often are balancing extra responsibilities (Roddy et al., 2017). They face similar challenges as traditional students but also endure additional stressors (Bourdeaux & Schoenack, 2016; Rivera-Vargas et al., 2021); the most challenging aspect for online students is balancing study with work, family, and caring responsibilities. However online learning may be time-efficient (Jaggars, 2014), it reduces traveling, and working at home can be better suited to one´s own of learning.
Rahmani, Groot and Rahmani (2024) reported that graduation rates are clearly lower from online programs than from programs offered in a traditional setting. Interactions in online learning present challenges. Dixson (2010) and Alqurashi (2019) point out the importance of recognizing that effective interaction occurs only if learning and instruction are well designed and implemented. Online studies also require self-direction and self-regulation, which may be particularly challenging for young adult students (Soffer & Cohen, 2019). Time management and organizational skills are also key factors that determine online student success (Farrell & Brunton, 2020; Rahmani et al., 2024).

### Instructional Support and Guidance

The flexible nature of online education enables adult students to integrate their learning with their other duties, provided that they are adequately supported (Rotar, 2022a). Instructional support and guidance for student learning are the key elements that can optimize student learning experiences in any learning environment (Lee et al., 2011). Instructional support and guidance include, but is not limited to, answering students' questions and reminding them to turn in assignments. The instructor's presence is a vital factor that contributes to students' online learning experiences (Caskurlu et al., 2021), and students´ perceptions of teaching presence affect their engagement (Gökoğlu et al., 2024). The lack of interaction between instructors and students is one of the most outstanding disadvantages of online teaching environments, making students feel isolated (Saraç & Doğan, 2022). This article uses the term instructor as interchangeable with teacher to emphasize the teacher's guiding role.

The instructor's responsive communication and tailored help sessions (Lee et al., 2011), as well as timely, personal, and meaningful feedback, affect the progress of the diverse online student population (e.g., Rotar, 2022b). For example, for distance students, using different forms of feedback can best meet the needs of all students and offer them the opportunity to

engage with different technologies. Feedback helps to improve learning by informing students of their current achievements and guiding them toward meeting their learning goals effectively (Theobald & Bellhäuser, 2022). Students may not maintain their work efforts without instructor feedback, which assures them they are on the right track (Alqurashi, 2019). Thus, the role of the instructor is to provide support, guidance, and assistance to all students according to their individual needs.

Interaction with an instructor and peers significantly enhances students' online learning experiences (Soffer & Cohen, 2019), as instructors often represent the course (Roddy et al., 2017). Students want instructors who support, listen to, and communicate with them (Caskurlu et al., 2021). Earlier studies have shown that online students are prone to display higher engagement and satisfaction if they perceive the instructor's presence through interactive tools and if they have opportunities to interact with the instructor, other learners, and the learning content (Dixson, 2010; Gökoğlu et al., 2024).

## Peer Learning and Peer Support

Peer learning is communication between or among students for the purpose of exchanging and sharing information or ideas, doing group activities, and giving feedback to each other (Alqurashi, 2019). Getting peer feedback promotes learning, but reading the texts of peers is also a learning experience (Tsui & Ng, 2000). Both can occur with or without an instructor. As shown by Farrell and Brunton (2020), peer discussions and debate enhance students' learning experiences and deepen their understanding of the course content. However, some studies have found that students prefer instructor feedback over peer feedback (e.g., Martin & Bolliger, 2018).

As reported by Lee et al. (2011), peer support refers to peer-to-peer learning that involves students supporting each other on academic or non-academic issues. When peer learning works and social interaction becomes an important part of learning, the young adult students are more involved in helping other students and feel a sense of belonging to a learning community (Lee et al., 2011). Shepherd et al. (2024) found that while most adult students value a sense of community, some prioritize completing their degree over community engagement. Previous studies have highlighted the significance of successful interaction for learning from various perspectives in online studies. For example, Farrell and Brunton (2020) showed that the role of peers was valued as part of the learning experience and as a source of support. Dixson (2010) found that online students were more engaged in the learning process when they could interact with the instructor and their peers, and Holzweiss et al. (2014) noted that peer interactions enhanced students' understanding of the course material.

Evaluating how students perceive their learning is an important way to improve the quality of online courses in aspects such as course design, delivery, and evaluation and to enhance students' learning experience (Alqurashi, 2019). According to Repo et al. (2014), instructional support and guidance for adult students should be further developed in a student-oriented manner considering their life situation (age, educational background, reason for studying). Rotar's (2022a) systematic literature review also showed that more attention should be paid to the importance of student support in the future. The open university student population is more diverse than the group of degree students, which have been studied clearly more compared to open university students. The open university student population has a wide age range, they

have other responsibilities (work and family life), and not all are studying towards degree goals. More research is needed on students' experiences of learning and support in online studies.

The purpose of the study was to examine adult students' experiences of learning and instructional support and guidance in the Jyväskylä Open University Finnish online courses. The specific research questions were:

1. How do open university students experience their learning through online courses?
2. How do open university students experience the support and guidance in an online course?

## METHODS

### Research Context

An open university is a unique learning environment compared to a regular university because all citizens can begin their studies there, regardless of their educational background, profession, etc., but not widely researched argues Repo et al. (2014). Finland does not have one national open university, like Open University UK in Great Britain, but each university has own open university. The open universities in Finland offer teaching that is carried out based on the higher education institution's own syllabus (Opintopolku, 2024). Degrees cannot be completed in any open university in Finland, a large number of students study for a degree later. However, some students only study for further education or for fun, without any other educational goals. The open university offers university studies from all faculties, and they are low cost, or free of charge. The student population is therefore very diverse, as in other European open universities (Müller, 2013). In Finland, studying at an open univeristy is more common than in many other European open universities (Müller, 2013). The role of the open university as part of higher education studies has been constantly growing as a pathway to a higher education degree (Opetushallitus, 2025).

Studying at the open university takes place mainly online. The most common modes of study are "open book exams" (a web examination in which students are allowed to use their course material while the exam is being conducted), written assignments (essays), online courses, and classroom teaching. The online course usually consists of various tasks and materials accessed in an e-learning environment and conducted with a jointly shared schedule. However, the course can be completed regardless of the time and place. Some tasks are independent while others are done in a group. Participants in the course can receive instructional support and guidance, peer support and feedback.

### Participants

The questionnaire for the present study was sent to 960 students who had participated in Finnish online courses at the University of Jyväskylä. We received 182 responses. At the time of the survey, some students may have attended several open university online courses. However, the same respondent was only able to answer the survey once. Each respondent answered every question. The age gap was wide (from under 25 to over 64 years old), most (44%). The group was also diverse in terms of educational level, but most students had a master's degree (41%).

## Data Collection

The data were collected via a web-based (Webropol) survey, which was sent by email to all students participating in online courses at the open university. The questionnaire was developed based on previous research on online course experiences (Dobbs et al., 2017; Roddy et al., 2017) and interaction in online learning environment (Sher, 2009). The instructors of online courses sent a link to the survey to their students, and later one reminder message. The data was collected during the year 2019, just before the COVID-19 pandemic. Answering the questionnaire was voluntary. The respondents gave their consent to participate in the study by answering the questionnaire. In this study we focused on qualitative analysis of open-ended answers. The seven open-ended questions are in the Appendix.

## Data Analysis

Since thematic analysis has been considered as suitable for exploring experiences (Braun & Clarke, 2006), it was used in the present study. In thematic analysis, as in this study, the aim is not to create a new theory but to describe, analyze, interpret and report in detail the themes emerging from the material (Braun & Clarke, 2006). No predetermined coding frameworks or researcher assumptions were adopted. The first author read and reread the data and identified initial codes related to the research questions (1st phase "Familiarizing yourself with your data"; Braun & Clarke, 2006). The authors discussed the codes several times and generated themes (2nd phase "Generating initial codes"; Braun & Clarke, 2006). These themes were reviewed and named (3rd phase "Searching for themes" and 4th. "Reviewing themes", Braun & Clarke, 2006). The use of colours facilitated coding and thematization, for example, yellow marked codes and themes related to learning, and green marked codes and themes related to instructional support and guidance. In this way, two main themes related to research question 1 were interaction and profound understanding, and three main themes related to research question 2 were structure, flexibility, and instructional support and guidance. ("5th phase "Defining and naming themes", Braun & Clarke, 2006). The unit of analysis varied between a word, a sentence, and a longer passage. The sub-theme of the interaction was, for example, peer learning and discussion with other students. The last step of the analysis was the report. The information was in Finnish, because students were Finnish speaking, and the quotes in this article were translated into English by the authors and checked by native English-speaking professional.

# FINDINGS

## Students' experiences: Peer Learning Leads to Profound Understanding

The participants gained a strong experience of peer learning during their online studies. **Peer support** came up in several answers, such as: "In the online course, I get advice and encouragement from peers..." Advice and encouragement from peers were mentioned in several responses, but only a few responses opened up further about them. Apparently, peers were more excited about the subject being learned, as is evident from one answer: "Discussions with peers encourage us to investigate the matter in more detail..." Many expressions were

related to peer learning and interaction (e.g., "through interaction you can gain insights"). A sense of belonging was also mentioned: "... you get the feeling of belonging to the student community."

**Discussion and working with peers** can be fruitful and rewarding. For example, through discussion, students can obtain practical experiences from working life. In addition, interaction with peers enhanced the understanding of the subject being studied, as one participant explained: "I feel that the contents of the course are easier to understand through conversations than by thinking alone, and the contents stick in my mind..." In the online course, the students feel a necessity to stick to the schedule and complete the tasks on time because doing this also affects the progress of the studies of their peers: "… working with others helps to complete the studies quickly." The fact that a student in an online course is accountable to others and must think about the progress of peers means that the interaction with others also promotes the student's own study: "The progress of the course requires everyone's participation and work input, interaction, and sociality. I can't get anything done alone."

In addition to support and working with peers' online communication was found to be easier. Giving **peer feedback**, and especially expressing an opposite opinion or view, may be easier online than in face-to-face interactions in the classroom, as one comment made clear: "Some conversations succeed even better online than face-to-face. For example, it may be easier to present criticism in peer review discussion."

According to findings, understanding and internalizing the things being studied are important in learning. When participants are students at the open university, they usually already have substantial study and work experience, which can be seen, for example, in how they can reflect on their learning and how they benefit from interaction with their peers. The participants described their learning using several expressions, including "profound understanding," "development of thinking," "understanding of broadened entities," and "internalizing the subject from different perspectives." Learning with peers was described, for example, in the following way:

> A variety of tasks and the progress of studying ... so that it leads the student to a more comprehensive internalization of the subject, working with other students. It is interesting to hear different points of view on the subject being studied. It deepens and broadens the understanding of the subject, and through it, you have to invest more in reflectivity and reflective thinking; it forces you to think about things more broadly and from many perspectives …

According to the results, online students experienced that interaction could promote learning and often reflects positively on their grades: "Interaction with other students and the teacher clearly broadens, deepens, and improves my understanding of the subject I am studying. This is also reflected in the grades..."

Thus, issues related to peer learning are clearly considered to lead to a profound and broad understanding of the subject of study. Studying for an exam is often seen as the opposite of interactive and in-depth learning. Students usually study for an exam by reading books or learning material alone, when things may be studied superficially and learned by heart. One student described it like this: "The topics studied were discussed extensively and in such a way that you really understand them. My thinking developed in a completely different way [in an online course] than, for example, when I was studying for an exam in a panic."

The peer learning experience was mainly seen as supporting learning; however, some contrary observations were made. For example, some participants felt that other students or their comments could not always be trusted, and the correct answers could remain unclear, as shown in the following example: “Since there were no instructor’s comments in all courses, it was sometimes difficult to know whether the things written by other students were right or wrong. That is, do you trust the answers of others or not...”

In open university studies, the principle is that everyone, regardless of age, background education, etc., can participate in courses. However, this diverse background caused frustration: “There are also too many other students on the online course who have weaker learning and study skills than I do. Guiding them by the instructor also takes time.” Although the online interaction was mostly satisfying, some students found it superficial: “An online course is certainly intended to create more dialogue between students, but in an online environment and when people have never met before, that dialogue can remain minimal...”

Some students had difficulty in publishing their own creations/texts for (strange) fellow students to see: “I noticed in this course that I wrote answers all the time thinking about what other students would think [about them] …” The difficulty in publishing one’s own texts for others to see arose from the fact that the interaction remained superficial or because the student was not used to this kind of interactive way of studying, where at least part of the tasks/texts are visible to everyone. Students could also stress their skills, especially at the beginning of their studies. If the students participating in the online course know each other from before, the interaction can feel more natural and easier in the online course.

## Instructional Support and Guidance Make Studying Easier

The students’ experiences of the instructional support and guidance were related to three themes: the (ready-made) structure of the online course, its flexibility, and guidance and the instructor’s presence. By **structure**, the respondents mean the common schedule and structure of the online course (i.e., the tasks must be done according to a specific schedule and often in a specific order). In this case, the tasks must be done on time, and the course can be completed more easily. This came up in several responses: “The advantage of the online course is also that I can probably finish my studies in the planned schedule; it moves like a train toward its destination…”

Concentrating on one subtask at a time is perceived as an easier and less intensive way to complete the course (e.g., in the middle of a busy everyday life). With this help, the most important subject to be learned is outlined, such as in exams, for example, when the student has to independently structure and manage large entities, as one comment shows: “[on the online course], studying is a little more guided and structured, so that the studies progress sensibly and on a faster schedule when there is a schedule created by the instructor. However, it is possible to complete the studies in smaller parts compared to exams.” Conversely, the online course is not necessarily offered throughout the academic year. Therefore, the online course does not always fit the students’ schedules, and the students must choose another mode of study if they want to progress in their studies.

The scheduling of the online course was described as suitably strict but also as giving the students the opportunity to go at their own pace. The schedule of the online course is rarely tied to the time of day or week, which makes it possible to participate in online courses while

working. The **flexibility** of studying is also mentioned in the answers related to support. Flexibility means that the students can study at their own pace: "The schedule of the online course structure [shows] what to do, but within the time frames, tasks can be done on the days of the week and at the times of the day you want." However, the finished schedule does not please everyone, as one student's comment shows: "I'm not motivated to study by the schedule given in advance...". Not everyone needs a ready-made schedule and (continuous) instructional support and guidance to progress in their studies, because they know how to manage their time and have self-discipline; therefore, progressing in their studies does not create challenges.

Naturally, flexibility also means that students can conceivably complete their studies remotely/at home. In this way, life situations (e.g., single parenthood) or weak financial situations do not become obstacles to studying, as one student concluded: "It was really nice when the instructor gave real-time online lectures. There was no need to travel and stay (a plus from an economic and ecological point of view), and yet the teaching was interactive..."

Structure and flexibility are often factors in which the modes of study differ. Exams and written assignments are seen as the most flexible modes of study, and face-to-face teaching as the most binding method of performance, as one respondent summed up well:

> In the online course, the subject matter has been broken down into smaller parts and will be reviewed as planned and scheduled. It's not quite as free studying as reading for an exam or doing a written assignment (essay), but it's not as binding as face-to-face study.

The online course is therefore seen as an intermediate between traditional lecturing in a classroom and completely independent online learning: "I find online courses to be a meaningful compromise between face-to-face teaching and taking [open book] exams."

Online learning makes study possible, even if the student has health-related challenges or issues related to learning/studying that do not allow participation in classroom teaching. An online course seems to be suitable for many students, regardless of whether they have physical limitations or psychological challenges: "I don't like going to face-to-face lectures, too many distractions and trouble." The student later clarified that studying in the classroom makes it difficult for her to maintain attention and concentrate on studying, which is easier at home.

The online course is also a suitable mode of study when a student has for example a challenge related to reading: "I don't like long exams because I'm a slow reader." In an online course, the students can spend as much time as they want doing the assignments, within the deadlines. Accessibility and easily available instructional support and guidance in the online course emerged in particular in those answers that compared different modes of study. In this answer, a challenge related to the student's physical health (joint problems) emerges:

> The schedule was suitable and the online course as a new way of studying seemed suitable for me, with its flexibility and support. This mode of study was easier for a person who is suffering from joint problems than a long continuous written exam. Now I can write in shorter periods…

Usually, the instructor does not even get to know whether the students have special needs. The student's disability or special feature does not necessarily affect studying in the online course at all. This is what a student with a hearing impairment said: "[in the online course], chat and written dialogue is sometimes easier when you are hearing impaired [than during face-to-face teaching, for example] when you don't have to struggle with hearing..."

In addition to the structure and flexibility of the online course, the answers by the online students regarding support are related to **instructional support and guidance** and **the instructor's presence**. Students feel that asking for advice is easier in an online course than when studying in other modes: "The instructor is more approachable, low threshold to ask for advice..." As explained by the students, support and guidance is more accessible in an online course than when studying in other modes of study: "Of course, guidance is more easily available [in an online course] than, for example, when writing an assignment." Discussion forums, called course cafés in Moodle's learning environment, make asking questions and requesting guidance easy during the course: "It's easier and faster to approach with a question. You can also get advice without asking through the [course] café."

In online courses, the instructors guide the entire group of students in common, but they also provide individual instructional support and guidance as needed. In addition, the instructor usually ensures that all students stay on schedule and return assignments to the right place at the right time, as shown in the following example: "Each task had separate detailed instructions, which was good. If I missed a task ..., I was personally contacted."

In the online course, the instructor's role emphasizes guidance and support. The learner is seen as an active processor of information and not as a passive recipient of knowledge (King, 1993). Some students may perhaps expect this as well in an online course, as the instructor guides the discussion and tells the "right answers." One student thought about the instructor's guiding role as follows:

> In my opinion, studying is also something that opens the fact that you can talk to an expert instructor about the subject and thereby get something out of it that might not be noticed by your classmates or your own thoughts. But I understand that it is a conscious solution that this is not realized in this mode of study, that the teachers are more in the background, serving a guiding role.

All students may not yet be used to the fact that one right answer or solution may not exist for everything, and that you can learn from peers even better than from an instructor. The open university students usually have substantial work experience; thus, peers can obtain practical examples from working life and different perspectives on the topics discussed.

Instructors' feedback practices also vary in online courses. Not all students were satisfied with the feedback they received on the online course. Some would have liked more - and more detailed - feedback:

> I would have liked more feedback on the exam and individual tasks. The feedback in some way makes you more committed to the course when you know that the evaluator has spent time reading the task that was done with effort.

In all courses, the student may not get personal feedback from the instructor, at least on all assignments. One student thought the joint feedback was not sufficient: "I don't get as much out of the joint feedback of the online courses as I do from the feedback of the written assignments, and the determination of the grade is therefore not particularly clear." In addition, not all students find peer feedback reliable:

> I received feedback on the interim assignments, and in them, the instructor guided me on what should be done differently or more in the future. I received no other guidance. I would have missed the instructor's commentary and guidance in group discussions. The interpretations of the texts in the group discussions seemed "wild" at times. The "correct" interpretations were left unresolved.

Grades were also a concern in an online course. The answer of one student indicates that the grade from the course tells more than just the approved performance:

> This course did not give grades but was assessed as pass/fail. When I received a grade from the online exam, I realized that I would have also needed feedback that would have focused solely on my areas of development. That way, I could have prepared those parts more and the exam would have gone better...

That students receive instructional support and guidance during the online course and not only at the end of the course was also perceived as important: "I would have needed more support for the fact that the grade did not become my own goal, and I would have hoped for information during the course that the performance was not sufficient." The student may also consider face-to-face feedback to be the best:

> The best feedback I've received has been personal feedback given face-to-face, where I've really had time to focus on, for example, the content and structure of the returned essay, as well as broader written feedback on my own text. In guiding an online course, the guidance will inevitably be a little more "faceless."

In an online course, feedback can be given face-to-face, although remotely. However, in open university studies, written feedback is the most common of all delivery methods, including courses held as face-to-face teaching.

## DISCUSSION

This study involved a typical group of open university students (e.g., varying in age, educational background, and experiences with online learning). Online learning can therefore suit the needs of a diverse group of students since it can meet many different needs (e.g., Martin & Bolliger, 2018). The aim of this qualitative study was to collect experiences of the adult students of open univeristy when they studied online. Supporting a diverse student body in online learning is necessary (Rotar, 2022), demanding, and therefore knowledge of their experiences can help develop it (Alqurashi, 2019). According to this study, students' experiences of learning in online courses are enhanced by interaction with the instructor and peers, and learning is facilitated by instructional support and guidance.

### Interaction as an Important Element in Online Studies

The findings of this study revealed that the role of peers is an important part of learning experiences, and that fellow students serve as a source of support in online courses. Peer learning can be a worthwhile and valuable part of a student's online course experience (e.g., Soffer & Cohen, 2019). As reported by Farrell and Brunton (2020) and Holzweiss et al. (2014), discussion and debate with classmates enhanced student learning experiences and profoundly enhanced their understanding of the subject being studied. In addition, a learning environment that encourages the sharing of learning experiences builds a sense of community among students and supports teamwork (e.g., Caskurlu et al., 2021). Interaction with the instructor and peers also allows for better engagement in the learning process (Holzweiss et al., 2014). Clearly, the online courses of the open university have been successfully built in such a way

that interaction and learning with peers are seen as important and functional elements in learning.

Some students wanted to complete their studies independently and use the time reserved for studying efficiently without interacting with peers. Therefore, the availability of different modes of study is important, allowing the students to choose the most suitable mode when options are available. However, it may sometimes also be good if the students try a mode of study that is not already familiar to them. For example, writing an essay develops abilities in scientific writing. The online course emphasizes peer learning and interaction. Open book exams require students to be able to study independently.

There are studies that indicate that students feel that the interaction between the instructor and the student in online studies is more important than the interaction between the students themselves (e.g., Caskurlu et al., 2021). The need for peer support is not necessarily the same for open university students as it is for young degree students, because the online students often already have permanent support networks in the form of family, friends, and colleagues (Martin & Bolliger, 2018; Repo et al., 2014). Interaction with peers can also be seen as an imposed requirement, rather than as a benefit (Caskurlu et al., 2021).

### Instructional Support and Guidance in Online

The schedule of online courses made it easier to study, as the assignments had to be completed on time. The instructor made sure that everyone returned their assignments on time and offered help if needed. The instructor's presence and guidance were therefore seen as important factors in online courses. This finding is in line with the results of previous research (e.g., Caskurlu et al., 2021). Students appreciate that the instructor answers their questions quickly, as they can continue their work when they get a quick answer to an issue that is bothering them. This idea has also emerged in previous studies (e.g., Lee et al., 2011).

In the online course, guidance is available as needed. Some students have good study skills and are therefore self-directed and self-confident. Although the students at an open univeristy are usually well-educated, their master's degrees may be very old, and they may find the use of information technology in online learning new and challenging, at least at the beginning of their studies. Today, technology is used in studying, but studying in other ways has certainly changed over the decades. Students' needs and expectations from guidance therefore vary and must be considered (Bourdeaux & Schoenack, 2016).

According to this study, receiving feedback from both the instructor and peers was considered important. Although peers are not as important for adult learners in terms of community as they are for young graduate students, receiving and giving peer feedback was felt to be important from a learning perspective. However, feedback from a teacher was perceived as the most reliable.

## CONCLUSIONS AND LIMITATIONS

The aim of this study was to study the open university students' experiences of learning and support in online courses. Interaction with both the instructors and peers was considered important. Instructional support and guidance, on the other hand, make studying easier.

Therefore, it is worth investing in these matters in the future and taking into account the diversity of the open university student population and their different needs. The participants are students from only one open university. Such a study could be conducted with multiple universities, including those from other countries than Finland.

The present study has some limitations that must be considered. Some of the respondents (16%) said that they only had experience with one online course, by which they only had experience with one type of online course. Consequently, their understanding of online courses may be weak, and they presumably compare their experience with more familiar ways of studying (i.e., face-to-face teaching). However, most of the respondents in the present study were experienced online students. Unlike elsewhere, the open university did not switch to online teaching due to the pandemic. The capabilities for online teaching already existed.

## IMPLICATIONS FOR RESEARCH

This study involved only a few students with disabilities or some other feature which affected their learning and/or studying, but they are present in open university courses. This study showed that interaction, instructional support and guidance are important for adult online students from different life situations in open universities´ online courses. Future research could focus on students who have difficulties in learning, disabilities or some other features which affect learning. It is essential to continue to monitor and meet the needs of students in the online environment so that online courses can adapt to changing future needs (e.g., Roddy et al., 2017). Knowledge of what kind of instructional support and guidance would best serve these students is crucial, since open universities are for all.

### Data Availability Statement

The research material is stored and processed in accordance with the information security and data protection practices of the University of Jyväskylä. This study is one of the partial studies of the dissertation. This DATA material will be destroyed when the dissertation is completed.

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## Appendix

The seven open-ended questions

Which subject did you study in the online course?

Why did you choose an online format to complete this course?

How do you think studying in an online course you have just completed differs from studying in other ways?

Are you planning to attend an online course in the future? Why or why not?

Comments concerning the instructional support and guidance you received.

According to your experience, how does the counseling you receive in an online course differ from the guidance you receive when you study in other ways?

What do you think is the best mode of study for completing a course in Open University (e.g., general exam, distance exam, learning assignment, online assignment, or online course) from the perspective of your learning and why?

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# OPERATIONAL HVAC ENERGY LOAD PREDICTION: EDGE-ORIENTED FORECASTING MODELS

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Abstract: *Contemporary office building standards require the installation of advanced HVAC systems, which, alongside industrial processes, are significantly responsible for energy consumption. While the literature describes numerous multi-parameter, deep artificial neural networks that are highly complex but poorly explainable (black box), commercial control systems must be based on simple-to-implement, easily adaptable intelligent predictive models whose reliability stems from their monitorability and explainability. The study verified several edge-oriented approaches using machine learning techniques for short- and medium-term predictions (1 day) with relatively high granularity (15 minutes). High granularity of time intervals, combined with high prediction reliability, not only provide a practical opportunity to optimize energy consumption, but also to increase the efficiency of renewable energy sources exploitation. Operational, high granularity predictions can also be used to detect anomalies and attacks, as required by modern cybersecurity rules.*

Keywords: *operational prediction, HVAC control, energy load forecast, edge computing, anomaly detection, cybersecurity.*


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# INTRODUCTION

## Problem Statement

In the Polish electricity sector, households account for only around 22% of total electricity consumption in 2024 (Polish Energy Regulatory Office, 2024). Since enterprises are responsible for the majority of demand, addressing their energy use is of critical importance. Recent macro-level studies confirm that understanding the socio-economic drivers of electricity demand is fundamental for accurate load-forecasting frameworks (Hlongwane, 2025; Krutsyak, 2019). A particular challenge and, at the parallel, the most anticipated scenario, lies in synchronizing energy demand with renewable energy supply. Nevertheless, the fluctuation of electricity demand throughout the day, combined with the unpredictable, weather-dependent (sun, wind, etc.) nature of renewable energy sources, make it difficult to manage and build effective interdependence without precise monitoring and planning of demand and supply processes. This issue considerably affects GHG emission and overall costs due to two main reasons. First, given the dynamic structure of Poland's energy mix, shifting demand or surpassing demand can allow for better correlation with green energy supply and contribute to a meaningful reduction in the carbon footprint. Second, aligning and balancing electrical loads can substantially lower electricity costs for enterprises. It is not surprising that energy producers and suppliers set tariffs in such a way as to counteract unexpected changes in supply and demand, which cause power grid overload and can lead to a complete power system failure (power outages). These aspects merit closer examination.

Poland remains among the European countries with the highest reliance on coal in its energy mix (International Energy Agency, 2024). However, the energy mix is not constant throughout the year, or even within a single day. Variations are primarily the result of changing contribution of renewable energy sources (RES), whose output fluctuates with daily and weather-related conditions. Consequently, conscious and well-planned balancing of energy demand throughout the day could lead to a substantial decrease in greenhouse gas emissions. By planning periods of increased RES supply and simultaneously planning load shifts to periods of increased RES availability, it is possible to achieve ecological synergies between green energy supply and demand. While certain operational regimes of enterprises are difficult or even infeasible to modify, significant opportunities remain. In particular, systems with high thermal inertia, such as heating, ventilation, and air conditioning (HVAC), offer considerable flexibility for demand-side management (Aslam, 2024). The global warming observed around the world means that air conditioning systems are becoming particularly common and increasing the load on energy networks. The development of alternative heat sources (heat pumps, etc.) is also shifting the load from coal and gas to electricity, which, with proper management, can be produced using renewable sources. In addition, the protection of company data must be taken into account, especially if it concerns energy consumption in various industrial processes. Data is a key company resource that must be strictly protected. Therefore, processing data on low-level edge devices rather than sending it to cloud servers seems to be a safer and more acceptable solution for

businesses. However, edge devices have limited resources and low computing power, which eliminates the use of large neural network models, even if they exhibit good predictive properties. The question remains, however, to what extent uncomplicated machine learning techniques allow for the prediction of high-granularity data.

Therefore, in this article, we argue that a reliable multi-step short-term (operational) electricity consumption forecast can equip small and medium-sized enterprises (SMEs) with simplified predictive models that do not require large resources and offer high operational and optimization efficiency. These, in turn, can not only reduce costs but also reduce the carbon footprint thanks to rationalization of energy consumption by exploiting the thermal dynamics of a building and shifting load of HVAC system. We validate this proposition through a simulation study of sample HVAC electricity consumption in an office building located in central Poland.

## Related Works

HVAC systems have been extensively studied by researchers in the context of both cost reduction and environmental impact mitigation. In modern buildings, they exhibit relatively high thermal inertia, which makes them well-suited for optimization and load shifting within building operation regimes. When thermal building dynamics are taken into account, optimizing power consumption can yield significant economic and environmental benefits.

The thermal dynamics of buildings can be modeled using three principal approaches (Balali, 2023):

1. **White-box approaches** — physics-based models such as detailed thermal dynamics equations (Xu, 2008) or simplified resistance–capacitance (RC) networks (Fraisse, 2002). These methods require extensive knowledge of both the building and the HVAC system.
2. **Black-box approaches** — data-driven models that discover relationships useful for forecasting, typically relying on large datasets. These methods disregard underlying physics but depend heavily on the availability of sufficient data.
3. **Grey-box approaches** — hybrid methods that combine physical knowledge with data-driven techniques, offering a compromise between model transparency and data requirements.

Since obtaining comprehensive and detailed information about a building is rarely feasible, thermal dynamics are often modeled using black-box or grey-box approaches. This is mainly due to the fact that the physical parameters of a building are used during its design, whereas after construction, the physical conditions may change and, what is more, the characteristics of a building change over time and depending on how it is used, which does not always correspond to the assumptions. Provided that the thermal inertia of a building (including HVAC response delays) can be modeled with sufficient accuracy, the HVAC central unit can anticipate future demand driven by occupants or outdoor conditions. This enables proactive control strategies that significantly reduce heating and cooling costs (Verbeke, 2018). When coupled with an environmentally friendly energy mix, such

approaches can also lower the environmental footprint of HVAC operations. This principle lies at the core of Smart Grids and demand-side management in electricity networks.

Beyond the direct benefits to HVAC system owners, large-scale implementation helps smooth the electricity demand–supply curve, thereby stabilizing the grid. A stable grid is more predictable, reducing the need for costly on-demand generation and preventing avoidable GHG emissions (Koebrich, 2025). Hence, precise modeling of thermal dynamics is critical. Using grey- and black-box approaches, the dynamics can be reasonably captured by combining outdoor conditions (such as air temperature, solar irradiation, and wind) with the power consumption of the HVAC system. Olu-Ajayi et al. (2025) point out that, in addition to weather conditions, the authors attempt to take into account the occupancy of the building, which intuitively seems to be a significant modelling factor. Since weather variables can typically be forecasted with acceptable accuracy over short- to medium-range horizons (Lam, 2023), the main challenge lies in forecasting the electricity consumption of the HVAC central unit multiple steps ahead. Characteristics of the HVAC control systems show that forecasts should have adequate granularity, both in the short and mid-term horizons. However, the definition of adequate granularity is imprecise, even in the domain of energy forecasting. Although formally adequate granularity predictions are located between seconds and days (Chen, 2022), the vast majority of authors (Olu, 2023) understand it as hourly or even longer time windows what diminish practical application of research. The need to shorten prediction granularity was raised, among others, by (Amasyali, 2018; Wang, 2017). It is worth noting, however, that demand response or operational system optimization requires rapid computational iterations of control algorithms. In addition, energy suppliers in Europe use a quarter of an hour as the billing unit, integrating instantaneous energy consumption characteristics from a fifteen-minute interval, following European legislation in the minimum operational granularity of energy market. These arguments clearly indicate that a thorough analysis of the ability of operational, 15 minutes granularity, short and mid-term forecasting models to predict energy (power) consumption should be carried out, which is the contribution of this study. It is worth verifying the forecasting capabilities not only for the nearest forecasting horizon but also examining the accuracy of medium range forecasts — several hours up to one day. It should be noted that among the many available forecasting models and techniques, we will pay particular attention to solutions that are simple and resource-efficient, as implementing solutions industrially, while maintaining appropriate security standards, requires their installation in a computing fog that does not have the same resources as typical servers. Addressing this challenge represents a pivotal milestone toward practical reducing GHG emissions. That also provides SMEs with sufficient time to plan and respond to changing circumstances efficiently.

One of the most elementary forecasting methods is the persistence model, which is widely used as a benchmark for comparison with more sophisticated approaches. It is defined as in (1), meaning that the forecasted values are identical to the most recently observed ones (Jung, 2014).

$$\overline{P(t+h)} = P(t), \tag{1}$$

where $\overline{P(t+h)}$ is a forecast at time *t* made *h* steps ahead (i.e., forecast of a value observed at time *t*+*h* made at time *t*) and $P(t)$ is an observed value at the time *t*.

Although extremely simple, in some cases it is sufficient. Its strength lies in computational simplicity, but its accuracy depends strongly on the characteristics of the time series being modeled. For short-term forecasts in stable environments (e.g., monotonic, smooth, or slowly varying series), the persistence model is often adequate (Das, 2018). For forecasting steady-system active energy consumption, short-term persistence forecasts can be valid, whereas for highly oscillatory power signals in real and dynamic systems, the method rarely performs well and predictions it does for multi-step forecasting usually does not reflect the reality. Though its performance is highly constrained, we selected persistence model as one of the reference forecasting methods, following the common practice in the domain.

To overcome the limitations of the elementary persistence model, many statistical approaches have been developed. Among the most widely applied are the autoregressive integrated moving average model (ARIMA) and its seasonally extended variant, SARIMA (Szostek, 2024; Kumari, 2024). Both models are linear and autoregressive, relying on lagged values and lagged forecast residuals to improve forecasts. However, they also have important limitations. In addition, both ARIMA and SARIMA demand careful parameter selection, which can be challenging to automate effectively. ARIMA has been one of the traditional models used for electricity consumption forecasting; nevertheless, both the basic and seasonal variants can sometimes produce unsatisfactory results when the data exhibit strong trends or irregular seasonal patterns (Klyuev, 2022).

Among other popular data-driven artificial intelligence models, two widely applied and successful approaches are based on random forests (Ho, 1995) and, even more successfully, on gradient boosting regressors (Friedman, 2001). Both methods follow a supervised, ensemble-based machine learning paradigm (Afzaal, 2023). They have been extensively applied in forecasting tasks, particularly in climate modeling (Khan, 2024) and electricity consumption forecasting (Di Persio, 2023; Magalhães, 2024). A major advantage of these techniques is the transparency of parameters and reasonable size, allowing models to be installed on edge devices.

Even more complex and sophisticated methods are based on artificial neural networks (ANNs), which have been widely adopted across industries and research domains. Even in their simplest form, the two-layer nonlinear perceptron, they offer remarkable flexibility and expressive power proved by means of universal approximation theorem (Selmic, 2002) for smooth functions. However, this potential comes at the cost of complexity, since ANNs involve numerous hyperparameters that must be carefully optimized, even though that optimization (in many cases) can be automatized.

The popular approach to predicting energy consumption time series is based on LSTM networks. Sendra et al. (Sendra, 2020) address the issue of next-day energy demand for HVAC systems, which significantly supports Demand Side Management in Smart Grids. The most relevant example of forecasts, reaching 24 hours with 30-minute granularity, is the paper by Fan (2019). The authors verify RNN, LSTM, and GRU recurrent models for predictive control solutions for intelligent HVAC system operations. The main contribution

was the use of the better properties of modelling dependencies in time series by LSTM and GRU models and reducing the impact of the last prediction error, which was propagated recursively to subsequent prediction horizons in reference solutions. As a result, more distant forecasts were increasingly further from the truth. Although the authors contest the usefulness of feed forward networks (FFN) or traditional machine learning methods in similar tasks, they focus exclusively on recurrent models and do not compare them with FFN. That requires skepticism about the superiority of developed RNNs methods with respect to FNN, especially taking into consideration higher sensitivity of RNN to hyper-parameters selection than FNNs. The paper by Song (2024) provides a comprehensive overview of deep learning methods for time series prediction, using energy consumption data as an example. Several dozen AI models, including statistical, recurrent, convolutional, transformer-type, and fully connected networks, were compared for predictions reaching several days ahead, but with one-hour granularity. In addition, attention was drawn to computational and operational complexity, which is an obstacle to learning and adapting predictive models in a commercial, specifically in the context of edge-oriented deployments. To diminish the importances of both obstacles, we selected a multi-layered perceptron as ANN representative for multi-step time series forecasting. It provides less parameters resulting in shorter training and retraining (for online procedures) phases. Furthermore, it comes with easier and more robust tuning procedures and, what is essential for commercial automatic and semi-automatic systems, it provides more interpretability than recurrent ANN.

## METHODS

To ensure credibility of experimental studies and simulation, we partially adapted the three-pillar methodological framework proposed by Walczak (2025) to focus on core elements: open dataset, complementary quality measures, and adequate experimentation protocol.

### Used Datasets

In our studies, we used the custom dataset acquired from main HVAC device operating in an office building located in Lodz (central Poland). The dataset contains four electricity characteristics all of which are described in detail in Tab. 1. However, in further studies, we only use two basic characteristics of active power, namely that which reflects the actual operational load on the network and active energy as the total energy consumption.

**Table 1.** Characteristics of the Dataset Used in Simulation Studies

| Name | Unit |
|---|---|
| Active energy | kWh |
| Reactive energy | kVarh |
| Active power | kW |
| Apparent power | VA |

The entire dataset covers the period between 1st July 2023 and 30th June 2025 with the temporal resolution of one minute. Measured values have been interpolated by monitoring system to align with full minute time index (e.g. 22:10 instead of 22:09:47). The dataset comes with the predefined train-test split following blocking strategy (Roberts et al., 2017) suitable for data with temporal dependencies: training split encompass data between July 2023 until the end of December 2024, the remaining contiguous part constitutes the test split.

Particular attention was paid to forecasting the active power characteristic, as it represents the instantaneous electricity demand, which makes it extremely useful for operational demand response and facilitating grid stability. Furthermore, unlike energy, active power is not monotonic, it exhibits peaks and ramps, which makes forecasting more challenging.

## Adopted Quality Measures

In our studies, we carried out an extensive comparison of reference forecasting methods, using complementary quality measures elaborated in this section. The first measure applied was the Mean Absolute Error (MAE), defined as

$$MAE = \frac{1}{n}\sum_{t=1}^{n}\left|P(t) - \overline{P(t)}\right|, \tag{2}$$

where $P(t)$ denotes the observed value of the time series at time *t*, and $\overline{P(t)}$ is the forecasted value at the same time, and *n* is the length of the time series.

MAE is more robust to outliers than the Mean Squared Error (MSE), and therefore results tend to be more stable. However, MAE (like MSE) is unbounded, and its magnitude alone does not directly indicate whether a forecast is accurate or note. To address this limitation, we followed Chicco (2021) and additionally used the coefficient of determination $R^2$ (3) and the symmetric Mean Absolute Percentage Error (4), sMAPE, which are more informative and bounded. Specifically, $R^2$ is bounded within $(-\infty, 1]$, whereas sMAPE — $[0, 2]$. It is important to note that MAE and sMAPE represent error measures, thus, lower values indicate better forecasts. In contrast, $R^2$ reflects the proportion of explained variance, so higher values indicate better forecasts.

$$R^2 = 1 - \frac{\sum_{t=1}^{n}\left(\overline{P(t)} - P(t)\right)^2}{\sum_{t=1}^{n}(P(t) - \dot{P})}, \tag{3}$$

where $\dot{P}$ denotes the arithmetic average of the observed values.

The symmetric Mean Absolute Percentage Error is given by (4):

$$sMAPE = \frac{1}{n}\sum_{t=1}^{n} \frac{\left|P(t)-\overline{P(t)}\right|}{0.5\cdot\left|P(t)+\overline{P(t)}\right|}. \quad (4)$$

## Data Clearing

After carefully examining the dataset, we identified suspicious values in the power readings. Considering the nominal power of the HVAC central unit from which the data was collected, the time series displays two peaks that exceed the valid operational range. The values from these peaks surpass the maximum power declared by the manufacturer by an order of magnitude. Therefore, as these values are more likely result of monitoring system malfunction rather than genuine anomalous observations, we trimmed the portion of data between 5$^{th}$ and 16$^{th}$ May, treating this segment of the characteristic as missing values. Missing data can be supplemented with interpolation or extrapolation techniques, but for the purposes of the experiments described, only recorded data was used.

## Forecasting Method

In this section, we present the approaches employed for predicting the values of active power and active energy *h* steps ahead, where one step corresponds to a 15-minute interval (resolution of time series, aligned with European policy for electricity billing). The experiments considered forecasting horizons of $h$ = 1, 4, 8, 48, and 96 (i.e., 15 minutes, 1 hour, 2 hours, 12 hours, and 24 hours ahead, respectively). Two backward window lengths were examined: $L$ = 96 (one day) and $L$ = 480 (five days), both with a 15-minute sampling granularity. The latter case was included to allow the model to capture weekly patterns. Five days are sufficient because the network can infer the day of the week from the observed sequence of values (e.g., after five working days comes Saturday, after three working days followed by two non-working days comes Monday, etc.). A separate model was fitted for each ($L$, $h$) pair. To select the optimal model (i.e., the optimal hyperparameters), the training dataset was partitioned into a training subset and a validation subset in an 80% to 20% ratio, and the generalization performance was assessed on the validation set.

As a reference, a naive persistence model (eq. 1) was used for both active power and energy. It forecasts the value observed at time t as the prediction for t+h. Such a baseline is often competitive at very short horizons and whenever clear cyclic patterns align with the horizon h (e.g., quarter-hourly or daily repetitions). It does not account for trends, regime changes, or exogenous shocks, so its accuracy typically deteriorates as *h* grows or conditions shift.

The first trained model was a two-layer perceptron (MLP), as it constitutes a universal approximator when equipped with a sufficiently large number of neurons in the hidden layer. In the experiments, different numbers of hidden neurons (the $K$ hyperparameter) were considered: 1024 and 2048, to ensure adequate flexibility and to avoid potential underfitting. The number of network inputs was equal to the number of historical measurements used for prediction (the $L$ hyperparameter). Two training strategies were adopted. In the first, termed

*single*, the network predicted only a single value corresponding to the specified forward step and therefore had a single output. In the second, termed *multi*, the network predicted all intermediate samples up to the specified forward horizon, with the final value taken as the prediction. This approach was intended to investigate whether the additional intermediate prediction tasks could improve performance (serving as a form of regularization). In this case, the network had $h$ outputs. It should be noted that for $h$ = 1, both strategies are equivalent.

To eliminate the influence of potential fluctuations in the time series and to normalize the network inputs, thereby facilitating more effective training, the input data was standardized. Standardization involved subtracting the mean and then dividing by the standard deviation, with these statistics computed separately for each processed input sample. Furthermore, to mitigate overfitting (which is possible due to the large value of the $K$ hyperparameter), a strategy was adopted to select the model with the best generalization ability. Generalization performance was evaluated on the validation set by monitoring the minimum mean squared error (MSE) achieved during training. Since the outcome of artificial neural network training depends on the initialization of weights, each experiment (with fixed hyperparameters) was repeated five times to enable a more reliable assessment of model performance. For all training runs, the maximum number of epochs was set at 5,000. However, to accelerate computation, early stopping was employed with a patience parameter of 100 epochs, meaning training would terminate if no improvement was observed within this window. Optimization was carried out using the Adam algorithm with a learning rate of 0.001. Three loss functions were considered for training: the standard MSE loss, the MAE loss, and the Fair loss with scaling parameter equal to 1.0.

To complement the perceptron approach, forecasts of active power and active energy were also generated using linear regressions whose coefficients were estimated using the ordinary least squares (OLS) and two ensemble methods: random forest (RF) and gradient boosting regressors (XGB). The primary advantages of OLS is straightforward interpretability and low computational complexity. However, OLS is limited in that it cannot capture the nonlinear relationships that are likely present in the analyzed time series. Therefore, we also included ensemble methods. For both active power and energy, we specified the models with lagged first differences of the series as regressors, consistent with the perceptron configuration.

For active energy, an alternative target was adopted for the classical models. Specifically, for OLS, RF and XGB, the target was reformulated as the cumulative increase from $t$ to $t + h$, i.e., $\hat{P}(t, h) = P(t + h) - P(t)$. The energy forecasts were then reconstructed by adding the predicted increase to the last available meter reading. In contrast, the MLP variant directly predicted the future meter level.

Hyperparameters for the ensemble models were selected on the validation subsample using RMSE as the primary criterion. The final configuration was kept constant across all horizons and both targets: RF used 100 trees, and XGB used 100 boosting rounds with maximal depth set to six and learning rate equals 0.1. OLS included an explicit intercept and did not require hyperparameter tuning.

## RESULTS AND DISCUSSION

Tab. 2 and 3 present the prediction accuracy metrics of active power and energy, respectively.

**Table 2.** Active power – prediction accuracy metrics

| Method | Horizon | MAE | MAPE | SMAPE | $R^2$ |
|---|---|---|---|---|---|
| Naive persistence model (k-1) | 1 | 0.01034 | 0.13908 | 0.10654 | 0.86692 |
| | 4 | 0.03023 | 0.49737 | 0.32733 | 0.49484 |
| | 8 | 0.04425 | 0.77747 | 0.49707 | 0.23183 |
| | 48 | 0.10322 | 1.70806 | 0.92971 | -1.58971 |
| | 96 | 0.05081 | 0.86738 | 0.54141 | -0.02348 |
| Linear regression (OLS) | 1 | 0.01384 | 0.21397 | 0.19148 | 0.90544 |
| | 4 | 0.03012 | 0.50079 | 0.37292 | 0.71834 |
| | 8 | 0.03700 | 0.63892 | 0.45294 | 0.61772 |
| | 48 | 0.04749 | 0.78777 | 0.52507 | 0.42785 |
| | 96 | 0.04514 | 0.76717 | 0.51685 | 0.47959 |
| Random forest (RF) | 1 | 0.01225 | 0.18640 | 0.15368 | 0.92992 |
| | 4 | 0.02124 | 0.35811 | 0.26593 | 0.83047 |
| | 8 | 0.02795 | 0.49600 | 0.34683 | 0.74579 |
| | 48 | 0.04006 | 0.75012 | 0.47411 | 0.57044 |
| | 96 | 0.04059 | 0.76784 | 0.48381 | 0.56427 |
| Gradient boosting (XGB) | 1 | 0.00857 | 0.12402 | 0.10781 | 0.95241 |
| | 4 | 0.01892 | 0.31529 | 0.23543 | 0.84181 |
| | 8 | 0.02547 | 0.44521 | 0.31507 | 0.75427 |
| | 48 | 0.03739 | 0.68144 | 0.44207 | 0.57140 |
| | 96 | 0.03725 | 0.68431 | 0.44657 | 0.57482 |
| MLP | 1 | 0.00980 | 0.14428 | 0.12601 | 0.93539 |
| | 4 | 0.02063 | 0.32686 | 0.27564 | 0.82232 |
| | 8 | 0.02674 | 0.47454 | 0.35102 | 0.75881 |
| | 48 | 0.03570 | 0.64144 | 0.42152 | 0.56776 |
| | 96 | 0.03625 | 0.60030 | 0.42868 | 0.54276 |

**Note.** Own calculations

**Table 3.** Active energy – prediction accuracy metrics

| Method | Horizon | MAE | MAPE | SMAPE | $R^2$ |
|---|---|---|---|---|---|
| Naive persistence model (k-1) | 1 | 0.02683 | 1.5e-06 | 1.5e-06 | 1.00000 |
| | 4 | 0.10734 | 5.9e-06 | 5.9e-06 | 1.00000 |
| | 8 | 0.21469 | 0.00001 | 0.00001 | 1.00000 |
| | 48 | 1.29025 | 0.00007 | 0.00007 | 0.99990 |
| | 96 | 2.58569 | 0.00014 | 0.00014 | 0.99963 |
| Linear regression (OLS) | 1 | 0.00346 | 1.9e-07 | 1.9e-07 | 1.00000 |
| | 4 | 0.02083 | 1.1e-06 | 1.1e-06 | 1.00000 |
| | 8 | 0.04532 | 2.5e-06 | 2.5e-06 | 1.00000 |
| | 48 | 0.30777 | 0.00002 | 0.00002 | 0.99999 |
| | 96 | 0.51115 | 0.00003 | 0.00003 | 0.99998 |
| Random forest (RF) | 1 | 0.00222 | 1.2e-07 | 1.2e-07 | 1.00000 |
| | 4 | 0.01171 | 6.4e-07 | 6.4e-07 | 1.00000 |
| | 8 | 0.02735 | 1.5e-06 | 1.5e-06 | 1.00000 |
| | 48 | 0.20484 | 0.00001 | 0.00001 | 0.99999 |
| | 96 | 0.33686 | 0.00002 | 0.00002 | 0.99999 |
| Gradient boosting (XGB) | 1 | 0.00225 | 1.2e-07 | 1.2e-07 | 1.00000 |
| | 4 | 0.01174 | 6.4e-07 | 6.4e-07 | 1.00000 |
| | 8 | 0.02700 | 1.5e-06 | 1.5e-06 | 1.00000 |
| | 48 | 0.20218 | 0.00001 | 0.00001 | 1.00000 |
| | 96 | 0.32721 | 0.00002 | 0.00002 | 0.99999 |
| MLP | 1 | 0.00503 | 2.7e-07 | 2.7e-07 | 1.00000 |
| | 4 | 0.01738 | 9.5e-07 | 9.5e-07 | 1.00000 |
| | 8 | 0.03399 | 1.9e-06 | 1.9e-06 | 1.00000 |
| | 48 | 0.19941 | 0.00001 | 0.00001 | 1.00000 |
| | 96 | 0.34444 | 0.00002 | 0.00002 | 0.99999 |

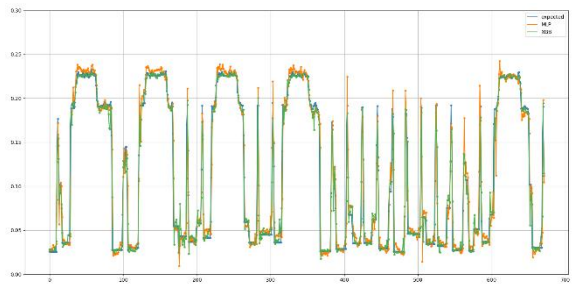
**Note.** Own calculations

On the active power task, XGB delivered the most accurate predictions across most horizons, particularly for short and medium ranges (15–120 minutes), where iterative residual fitting captures nonlinear interactions among recent differences. Random Forest consistently trailed XGB by a small margin and outperformed OLS at all horizons, benefiting from the longer backward window at larger *h*, which exposes weekly structure in the differenced domain. OLS, while linear and highly interpretable, nonetheless provided a solid improvement over the naive persistence benchmark, especially as the horizon lengthened and persistence deteriorated (including negative $R^2$ at 12–24 hours).

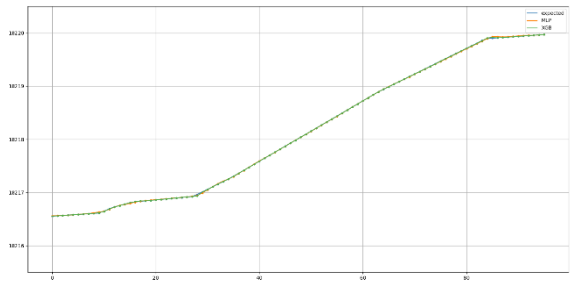
On the active energy forecast task, all methods achieved near-perfect fit ($R^2 \approx 1$) across horizons, including the naive persistence model. This outcome follows from the reconstruction $\overline{P(t+h)} = P(t) + \hat{P}(t,h)$, the last reading P(t) carries most of the level, and the model estimates only the residual increment. Consequently, differences among XGB,

Random Forest, OLS, and MLP were numerically small and operationally negligible. In this setting, OLS is generally sufficient for deployment unless marginal gains from tree ensembles or the perceptron are required by specific operational constraints.

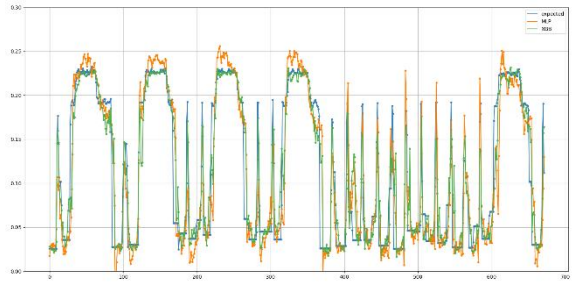
The MLP matched or slightly outperformed Random Forest performance at several horizons and surpassed OLS. For MLP, the experiments demonstrated that $K = 2048$ neurons constituted an excessive number for the data under consideration, with the best results obtained for $K = 1024$ hidden neurons. It is possible that, depending on the characteristics of the data, this number could be further reduced (resulting in computationally less complex models) without a loss in prediction quality. In all experiments, the *multi* strategy performed at least as well as the *single* strategy. The few cases where the best result was obtained with the *single* strategy occurred when $h = 1$, in which both strategies are equivalent. The observed differences arise from the randomness of neural network weight initialization. More accurate prediction of distant samples (larger $h$ values) requires a greater number of historical samples (larger $L$ values). With respect to the choice of loss function, it was observed that in the tasks under consideration, MSE loss generally performed slightly worse than the other two functions. It should be noted that Fair loss, like MAE loss, is based on the absolute differences between the expected and predicted values.



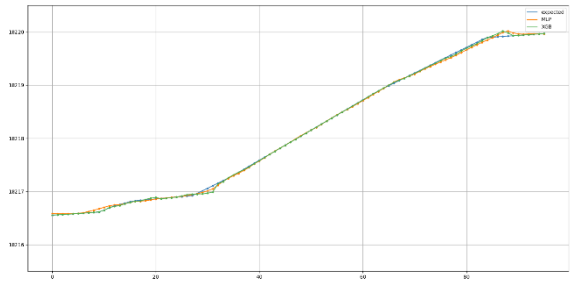
$h = 1$



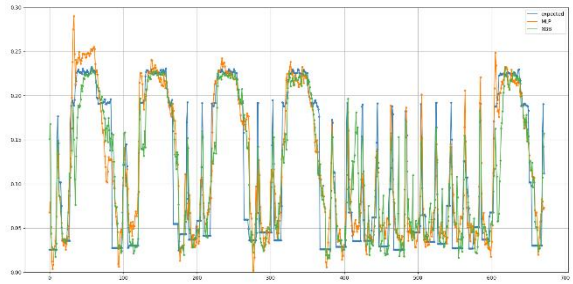
$h = 1$

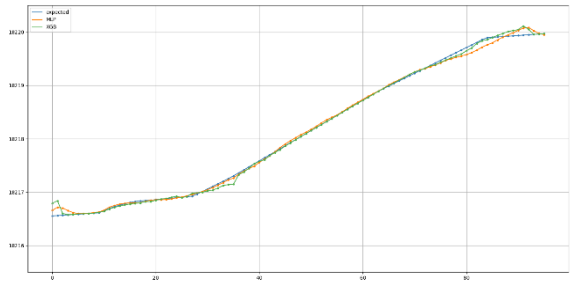


$h = 4$



$h = 4$





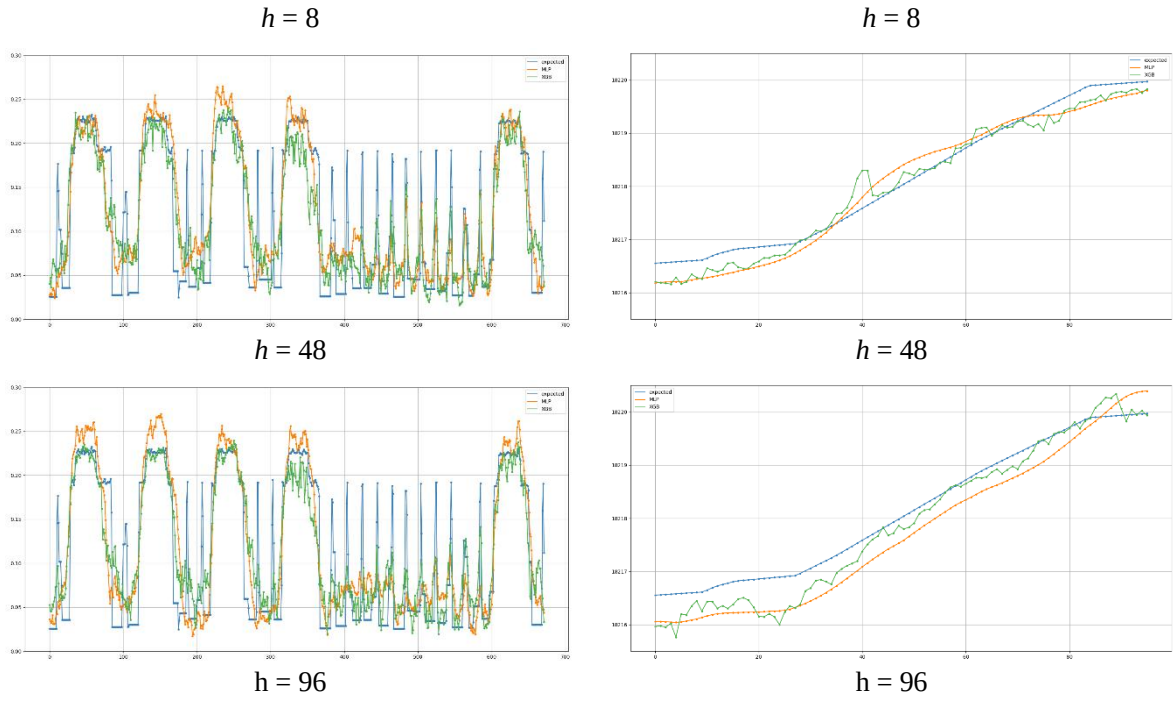



**Figure 1.** Sample predictions (XGBoost and MLP) of active power (left, 7 days) and active energy (right, 1 day) for different horizons *h* (XGBoost – green, MLP – orange, expected-blue).

The graphs presented in Figure 1 clearly demonstrate the relatively high accuracy of predictions, even for distant samples – a quarter of an hour distant by one day (96 samples). When forecasting active energy, no significant differences should be expected, as the function is clearly monotonic. This trend is best captured by a multilayer perceptron. On the other hand, the variability of active power is much better captured by XGBoost. Local peaks are visible even in distant forecasts, which is crucial when forecasting instantaneous loads on the electrical network. The reliability of forecasts is reinforced by the values of the error measures. For active energy, they are at a level that raises no doubts, while for active power, they show that the forecasts exhibit a trend of change, and incremental and successive updating of the forecasts allows for very high quality to be achieved.

In summary, for active power forecasting, XGB is recommended as the top performer, with RF a robust and stable alternative and MLP competitive when configured with a moderate hidden size. OLS remains a strong, transparent baseline that clearly surpasses persistence at longer horizons.

## CONCLUSIONS

Based on reported results, several conclusions can be made. Specifically, forecasting active energy is solved by all considered models good for all forecast horizons. The worse quality measures reach less than 1% of sMAPE and more than 0.99 for coefficient of

determination. That aligns with almost perfect forecast. It is not surprising as energy is monotonic function (it has no seasonality and trend is roughly constant). That confirms the high application potential of considered methods, in particular taking into account edge-oriented deployments of highly constrained memory and computational resources.

Active power, though in practice it is the quantity of energy use, is much harder to predict. It is yet not surprising either, as high oscillation and seasonality of data make finding underlying relationships challenging. Certainly, the difficulty increases while growing forecast horizon. In terms of sMAPE for the longest forecast horizon (i.e., 96 quarters ahead), the best result was achieved by MLP with metric value attained at the level of 42.9% whereas the worst for the naive persistence model (51.1%).

In overall, the presented forecast methods aligning with limited computational and memory resources available for edge deployments, provide predictions of sufficient accuracy to facilitate balancing the operational regime of HVAC systems.

## IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

High-granularity energy-consumption forecasting, including mid-range projections, is essential for understanding demand drivers and managing modern power systems. Popular "building intelligence" solutions, like e.g., smart homes, renewable-ready grids, and effective demand–supply control, depend on operational forecasts at 15-minute resolution (or finer); without such capabilities, reliable automation and optimization are not feasible.

Building-efficiency standards (e.g., net-zero/zero-emission requirements) demand precise monitoring and control of equipment to meet targets and pass routine audits. Without the forecasting approach discussed in this article, it is difficult to conduct the energy reviews and audits specified by ISO 50001 (energy management systems).

An interesting implication of high-granularity prediction, in the context of further research, is the possibility of comparing predicted energy values with current time series. This makes it possible to detect anomalies and attacks on energy systems. Aggregated energy data does not allow for the monitoring of anomalies and attacks on energy networks, which can be effectively detected and diagnosed by comparing finely granulated forecasts with actual electricity consumption characteristics. At the same time, the compliance of energy systems with European NIS and CRA directives imposes new requirements on energy network monitoring and management systems that go beyond the highly aggregated approach often found in the literature.

In summary, high-granularity monitoring and planning is an important research challenge with significant practical and strategic implications, both in the context of safety certification, energy audits, and the widespread shift towards ecology and increasing the share of renewable sources in the energy mix.

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# DOES AI VIBRANCY RESHAPE EMPLOYMENT STRUCTURES AND UNEMPLOYMENT? SHORT-RUN EVIDENCE FROM GLOBAL PANEL DATA

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Abstract: *This study examines whether national AI vibrancy affects employment structures and unemployment, utilising panel data for 36 countries (2017–2023) from the Stanford AI Vibrancy Index and World Bank indicators. Fixed- and random-effects models, along with Hausman tests and clustered standard errors, were applied. Results reveal no significant short-term effect of AI vibrancy on industrial or service employment, nor on unemployment. GDP per capita showed a modest positive effect on industry ($\beta = 0.046$, $p < 0.10$) and, in some models, on services ($\beta = 0.045$, $p \approx 0.06$). Labour force participation correlated positively with service employment ($\beta = 0.322$, $p < 0.10$) and negatively with unemployment ($\beta = –0.006$, $p < 0.01$). Strong time effects reflect pandemic-related labour shifts: industrial jobs declined, service employment grew, and unemployment spiked temporarily. Overall, labour dynamics appear driven more by global shocks and demographics than by AI vibrancy.*

Keywords: *artificial intelligence, AI vibrancy, employment structures, unemployment, labour force participation, panel data analysis.*


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## INTRODUCTION

Whether AI vibrancy is reshaping employment structures and unemployment is a highly topical issue, as international organisations warn of profound shifts underway in the global workforce. The International Monetary Fund estimates that AI could affect roughly 40 per cent of jobs worldwide, with around half of those roles benefiting from increased productivity. At the same time, the remainder might face reduced labour demand or job displacement, particularly in advanced economies (Cazzaniga et al., 2024). This underscores the dual nature of AI: a force for both augmentation and disruption.

Evidence from the International Labour Organisation adds nuance to this picture. While occupational exposure to generative AI is widespread, covering an estimated 24 per cent of global employment, jobs are more likely to be transformed than eliminated. Only a small minority, around 3.3 per cent, falls into the highest-risk category where AI could fully replace human tasks (Harrington, 2025). Still, the shift toward task transformation presents challenges, especially in administrative and clerical roles, where generative AI is acquiring capabilities once performed by human workers, a trend with potential gender implications. ILO reports highlight that women's jobs are disproportionately exposed to such transformation (Le Poidevin, 2025).

The World Bank notes that the impact of AI will vary across different development contexts. Low-income countries appear less exposed overall, owing to limited digital infrastructure and labour markets dominated by manual or interpersonal work, which are less amenable to AI automation. However, these economies also risk falling behind, as they may lack the capacity and policy frameworks to harness AI's potential (Demombynes et al., 2025).

These institutional findings underscore that AI's influence on employment is neither uniform nor immediate. Instead, it manifests unevenly across countries, sectors, and worker groups, with transformation often occurring within tasks rather than at the level of entire occupations. For a study examining AI vibrancy and aggregate labour outcomes from 2017 to 2023, such context highlights why large-scale employment shifts may not yet be observable, and why empirical analysis must account for complex institutional and structural mediators.

The relationship between AI, labour markets, and employment structures has attracted growing attention as digitalisation accelerates. Early contributions stressed the transformative capacity of AI and automation, with expectations that industrial employment would decline, services would expand, and unemployment might rise if labour could not adjust swiftly (Acemoglu & Restrepo, 2018; Autor & Salomons, 2018; Brynjolfsson & McAfee, 2014; Frey & Osborne, 2017; Sarker, 2022). Empirical findings reveal a more nuanced picture, with technological progress exerting complex and heterogeneous impacts across sectors, skill groups, and regions (Bessen, 2019; Fan, 2025).

A growing body of studies analyses how AI adoption interacts with human capital, competencies, and labour productivity. Research on emerging economies reveals that the macroeconomic effects of AI on labour markets may differ significantly from developed countries, with Bangladesh showing limited realization of AI's expected economic benefits due to insufficient AI robot integration across manufacturing and service sectors (Sarker, 2022). Research shows that the integration of AI reshapes tasks more than entire occupations, requiring employees to adapt by developing new skills while organisations adjust to maintain productivity (Bîrcă, 2025; Cramarenco et al., 2023; Istudor et al., 2024; Głód et al., 2025; Cham

et al., 2022). This task-level transformation is evident in sector-specific applications, where AI technologies such as machine learning, robotics, and IoT significantly improve operational performance in warehouses and logistics (Angammana & Jayawardena, 2022), while real-time monitoring technologies enhance efficiency in industrial operations by reducing non-productive time (Aneke & Oboho, 2024). Evidence confirms that AI increasingly complements knowledge-intensive jobs while challenging low- and medium-skilled roles, a shift which requires active reskilling strategies (Abid et al., 2024; Androniceanu, 2025; Bian & Wang, 2024; Pisică & Zaharia, 2025). At the same time, global labour markets reveal significant skill mismatches, where digital transformation outpaces the preparedness of education systems and training institutions (Butum & Nicolescu, 2024; Jarząbek & Stolarska-Szeląg, 2024; Jarzębowski et al., 2024; Roshchyk et al., 2024; Vorontsova et al., 2021).

Broader structural and demographic factors further influence the dynamics of employment. Studies confirm that productivity growth, output fluctuations, and employment exhibit complex bi-directional linkages, often amplifying labour market adjustment pressures (Butkus et al., 2024; Yurchyk et al., 2024). Other work highlights the differentiated exposure of groups such as youth, women, and persons with disabilities, whose participation in labour markets is mediated by urbanisation, inclusiveness, and targeted support policies (Bal-Domańska et al., 2025; Jarząbek & Stolarska-Szeląg, 2024; Moutik, 2025). Migration and remittance flows further shape labour supply and employment trajectories, particularly in transition economies (Denissova, 2025; Oliinyk et al., 2024; Peković, 2025; Privara, 2025).

The effects of digitalisation extend beyond employment levels to employee well-being, organisational performance, and governance structures. Studies indicate that digital transformation reshapes job satisfaction, stress levels, and work–life balance, while also introducing ethical challenges in law enforcement, traffic enforcement, and public sector decision-making (Haley, 2025; Haley & Burrell, 2025; Hernik et al., 2025; Mujtaba et al., 2025; Trembeczki et al., 2025; Welch, 2025). Similar challenges emerge in sectors such as agriculture and health, where digital competitiveness, governance, and AI-enabled systems drive both opportunities and vulnerabilities (Ernawati et al., 2025; Kuzior et al., 2024; Dobrovolska & Kolomiiets, 2024; Maró et al., 2024). The literature also shows that leadership, organisational politics, and employee engagement play a crucial role in mediating the adoption of AI and sustaining firm performance (Hussein et al., 2024; Kuzior et al., 2022; Liu et al., 2024; Mihajlovic et al., 2025; Urbański et al., 2024; Vuong, 2025).

Parallel streams of research highlight the impact of digitalisation on finance and economic sectors, where AI and fintech applications reshape employment opportunities and organisational strategies (DingYi et al., 2024; Hossain, 2025; Kozhushko, 2023; Lipták et al., 2023; Parajuli et al., 2024; Zada et al., 2024; Chandran & Ittimani Tholath, 2025). Similar dynamics emerge in influencer marketing and public services, where AI-enabled platforms transform competencies, infrastructure, and employment prospects (Pilelienė & Bogoyavlenska, 2025; Szedmák et al., 2025; Virlanuta et al., 2024; Wang et al., 2025). The broader socio-economic implications of AI adoption for equity, inclusiveness, and empowerment have also been addressed, with findings pointing to both opportunities for gender empowerment and risks of new forms of exclusion (Moutik, 2025; Yarovenko et al., 2024; Skrynnyk et al., 2022).

The COVID-19 pandemic created further complexity by accelerating digital transformation while triggering sharp disruptions in employment and unemployment. Real-

time survey evidence confirms that the shock had unequal effects across groups and occupations (Adams-Prassl et al., 2020). The pandemic exacerbated uncertainty in worker behaviour, migration patterns, and public health determinants, making labour market dynamics more volatile (Denissova, 2025; Dobrovolska & Kolomiiets, 2024; Trembeczki et al., 2025; Yekimov et al., 2022). Studies highlight that resilience to such shocks depends on both digital readiness and labour market institutions, which can buffer or amplify the employment impact of crises (Jarzębowski et al., 2024; Ualtayev et al., 2024).

The literature reveals a multifaceted landscape in which AI influences employment not through simple substitution, but via gradual task transformation, productivity linkages, and broader socio-economic and institutional contexts. While expectations of large-scale displacement remain prevalent, empirical evidence highlights the importance of complementary skills, labour market rigidities, and global shocks in mediating outcomes. These insights provide a foundation for testing whether AI vibrancy at the national level has exerted measurable effects on employment structures and unemployment in recent years.

This study aims to examine whether national-level AI vibrancy influences labour market structures and outcomes, specifically employment in industry, employment in services, and unemployment. By applying panel data methods to 36 countries from 2017 to 2023, the research aims to determine whether AI vibrancy has measurable short-run effects on sectoral employment shares and unemployment, after controlling for economic development, labour force participation, and time-specific shocks.

Based on theoretical expectations of technological change and labour reallocation:

- H1: Higher AI vibrancy is associated with a reduction in the share of employment in industry.
- H2: Higher AI vibrancy is associated with an increase in the share of employment in services.
- H3: Higher AI vibrancy is associated with higher unemployment rates, reflecting short-term displacement effects.

## METHODS

The study employs annual panel data for 36 countries from 2017 to 2023. Dependent variables include employment in industry (as a percentage of total employment), employment in services (as a percentage of total employment), and unemployment (as a percentage of the total labour force), all drawn from the World Bank's World Development Indicators (World Bank, n.d.). The key explanatory variable is the AI Vibrancy Score, sourced from Stanford University's Global AI Vibrancy Tool (Stanford University, n.d.), which measures national-level AI activity and ecosystem strength. GDP per capita (in constant 2015 US dollars) and labour force participation rate (as a percentage of the population aged 15–64) are included as control variables, also sourced from the World Bank database.

Variable transformations were applied based on Box–Cox tests to address differences in scale and non-normal distributions. The AI Vibrancy Score was transformed using a logarithmic specification, GDP per capita by square-root transformation, and unemployment through an inverse-root transformation. Employment shares and labour force participation

were maintained at their current levels. These transformations ensured more stable variance and reduced skewness in the data.

The empirical analysis proceeded in two stages. In the first stage, two-way fixed effects models were estimated, incorporating country and year effects. This specification controls time-invariant country characteristics (institutional frameworks, labour market traditions, or long-standing industrial structures) and global shocks standard to all countries (e.g., the COVID-19 pandemic). This step provides a baseline assessment of whether AI vibrancy exerts any measurable short-run effect on employment outcomes once unobserved heterogeneity is accounted for.

In the second stage, the analysis compared fixed effects (FE) and random effects (RE) estimators for each outcome variable. The FE estimator is robust when regressors are correlated with unobserved country-specific factors, whereas the RE estimator is more efficient if such correlation is absent. The Hausman test was applied to determine the appropriate specification. Where the test rejected the RE assumption, two-way FE models were retained as consistent estimators (as was the case for industry and services employment). Where the test failed to reject, the RE estimator was considered valid and was preferred for efficiency (as in the unemployment model).

All models were estimated with clustered standard errors at the country level to ensure robust inference, correcting for heteroscedasticity and serial correlation within panels. This specification provides more reliable significance tests in the presence of intra-country correlation over time. By combining two-way FE baselines with FE–RE comparisons, the modelling strategy provides a rigorous framework to isolate the role of AI vibrancy in shaping labour market outcomes while accounting for structural determinants and exogenous shocks.

## RESULTS

The descriptive statistics (Table 1) highlight apparent differences in scale and distribution across variables. The AI Vibrancy Score (x1) shows extreme dispersion: although the mean is 18.46, the standard deviation is more than four times larger (85.63), with values ranging from 0.34 to 1363. The skewness (15.36) and very high kurtosis (238.22) indicate severe positive skew and heavy tails. This suggests that most countries in the sample have low AI vibrancy, while a few exhibit very high values. Therefore, a transformation of x1 is necessary to normalise its distribution, stabilise variance, and reduce the influence of extreme outliers. The GDP per capita (x2) also exhibits substantial variation, with values ranging from below USD 2,000 to above USD 110,000. Although skewness (0.68) and kurtosis (0.18) are not extreme, the extensive range and cross-country heterogeneity justify a transformation for meaningful comparison and to mitigate heteroscedasticity. Labour force participation (x3) shows mild negative skew but remains within acceptable ranges.

By contrast, the labour market variables are relatively well-behaved. Employment in industry (y1) and services (y2) has moderate dispersion, with low skewness and kurtosis close to normality. Transformations are not strictly necessary for these variables. However, the unemployment rate (y3) is positively skewed (skew = 3.48, kurtosis = 14.25), indicating that while most countries maintain relatively low unemployment rates, some face very high levels.

For robustness, applying a log or square root transformation to unemployment may improve its distributional properties.

Transformations are strongly recommended for the AI Vibrancy Score (x1) and GDP per capita (x2), and are advisable for the unemployment rate (y3). The employment shares and labour force participation can be used in their raw percentage form without modification.

**Table 1.** Descriptive statistics of variables (2017–2023, 36 countries, N = 252) [Source: authors' calculations in R Studio]

| Variable | AI Vibrancy Score | GDP per capita (constant 2015 US$) | Employment in industry (% of total employment) | Employment in services (% of total employment) | Labour force participation rate, total (% ages 15–64) | Unemployment, total (% of total labour force) |
|---|---|---|---|---|---|---|
| Code | x1 | x2 | y1 | y2 | x3 | y3 |
| Mean | 18,46 | 39151,7 | 22,13 | 71,74 | 73,74 | 6,38 |
| Std. Dev. | 85,63 | 24860,4 | 4,91 | 11 | 7,06 | 4,89 |
| Median | 11,18 | 40501,4 | 20,53 | 73,88 | 74,69 | 4,99 |
| Min | 0,34 | 1788,7 | 9,19 | 31,02 | 54,37 | 2,15 |
| Max | 1363 | 110426 | 34,6 | 89,73 | 85,5 | 34,01 |
| Skewness | 15,36 | 0,68 | 0,06 | –1,59 | –0,83 | 3,48 |
| Kurtosis | 238,22 | 0,18 | –0,32 | 3,23 | 0,14 | 14,25 |

The estimated Box–Cox parameter (λ) is centred around zero, with the 95% confidence interval spanning zero (Figure A1, Appendix A). The Box–Cox plot for GDP per capita also shows that the optimal λ is close to zero, with the confidence interval encompassing zero but excluding one (Figure A2, Appendix A). This suggests that a log transformation of GDP per capita is statistically justified. The Box–Cox likelihood function for unemployment rate indicates that the preferred λ is between -1 and 0, with zero in the confidence interval (Figure A3, Appendix A). Box–Cox transformation tests were conducted for the AI Vibrancy Score, GDP per capita, and unemployment rate to improve the statistical properties of these variables and address issues of skewness. The results indicate that the estimated transformation parameter for the AI Vibrancy Score is $\lambda \approx 0.03$ (95% CI: –0.04 to 0.10), which is statistically indistinguishable from zero, confirming that a logarithmic transformation is appropriate. For GDP per capita, the optimal parameter is $\lambda \approx 0.50$ (95% CI: 0.36 to 0.64), rejecting both the log ($\lambda = 0$) and linear ($\lambda = 1$) specifications, which suggests that a square-root transformation provides the best normalisation. For unemployment, the estimated λ is –0.73 (95% CI: –0.94 to –0.51), with both the log and untransformed forms firmly rejected; this implies that an inverse-root transformation best corrects distributional irregularities. Accordingly, the AI Vibrancy Score is used in its logarithmic form, GDP per capita in the square root form, and unemployment in the inverse root form. At the same time, employment shares and labour force participation are retained in their original scales as their distributions are approximately symmetric.

The diagnostic statistics confirm (Table 2) that the chosen transformations substantially reduced skewness and excess kurtosis. The AI Vibrancy Score became nearly symmetric after log transformation; GDP per capita achieved approximate normality under square-root

transformation; and unemployment distribution was normalised through the Box–Cox inverse-root transform.

**Table 2.** Descriptive statistics before and after transformation [Source: authors' calculations in R Studio]

| Variable | Mean | Std. Dev. | Skewness | Kurtosis |
|---|---|---|---|---|
| AI Vibrancy Score (raw) | 18.46 | 85.63 | 15.36 | 238.22 |
| AI Vibrancy Score (log) | 2.25 | 0.97 | –0.17 | 2.58 |
| GDP per capita (raw) | 39,151.71 | 24,860.40 | 0.68 | 0.18 |
| GDP per capita (√) | 186.45 | 66.37 | –0.10 | –0.57 |
| Unemployment rate (raw) | 6.38 | 4.89 | 3.48 | 14.25 |
| Unemployment rate (Box–Cox λ≈–0.73) | 0.95 | 0.13 | 0.02 | –0.11 |

The results for employment in industry (y1) suggest that AI vibrancy (log-transformed, lagged) does not exert a statistically significant effect on the industrial employment share. However, the estimated coefficient is negative (–0.22). This indicates that, while higher levels of AI vibrancy might reduce industry employment, the evidence is not robust within this panel. By contrast, GDP per capita (square-root transformed) has a positive and significant effect on industry employment, implying that higher income levels are associated with a larger share of industrial jobs. Labour force participation shows a negative and significant effect, suggesting that as more of the working-age population participates in the labour market, the share of industry employment declines. The year dummies indicate a systematic decline in industry employment after 2019, consistent with global shocks such as the COVID-19 pandemic and subsequent economic restructuring.

For employment in services (y2), the coefficients display almost the mirror image of the industrial results. AI vibrancy is again statistically insignificant, with a small negative estimate. GDP per capita exerts a negative but non-significant influence. At the same time, labour force participation has a strong positive effect, indicating that increases in participation rates tend to expand the relative size of the service sector. The year dummies after 2019 show positive and significant effects, highlighting a structural shift towards services during and after the pandemic years. The findings reveal that the main drivers of service sector expansion are labour supply dynamics and year-specific shocks rather than AI vibrancy.

For unemployment (y3, transformed via the Box–Cox method), the results show that AI vibrancy, GDP per capita, and labour force participation do not exert statistically significant direct effects. Instead, unemployment dynamics appear strongly shaped by time effects. The year 2020 was marked by a significant rise in unemployment, reflecting the global impact of the COVID-19 pandemic. Elevated levels persist in 2021, while in 2022 and 2023, unemployment shows significant declines compared with the baseline, likely reflecting recovery policies and labour market adjustments. The model's explanatory power is relatively high ($R^2 = 0.44$), indicating that macroeconomic shocks, as captured by time-fixed effects, are more important determinants of unemployment than structural variables in this dataset.

The panel fixed-effects regressions suggest that the impact of AI vibrancy on labour market outcomes is limited in the short term. Rather than directly reshaping sectoral employment or unemployment, AI vibrancy may influence labour markets indirectly or over longer horizons. In contrast, labour force participation and income levels have stronger and more consistent associations with employment structures. Year effects are crucial in explaining

short-term fluctuations, particularly during the pandemic period, underscoring the importance of global shocks in shaping labour market outcomes in the 2017–2023 window.

**Table 3.** Two-way fixed effects regression results [Source: authors' calculations in R Studio]

| Variable | Industry Employment (y1) | Services Employment (y2) | Unemployment (y3_tr) |
|---|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.223 (0.153) | –0.056 (0.161) | –0.007 (0.007) |
| GDP per capita (x2_tr) | 0.046** (0.020) | –0.034 (0.021) | –0.001 (0.001) |
| Labour force participation (x3) | –0.198** (0.082) | 0.322*** (0.087) | –0.004 (0.004) |
| Year 2019 | –0.481** (0.209) | 0.511** (0.219) | –0.015 (0.009) |
| Year 2020 | –0.592*** (0.215) | 0.609*** (0.226) | 0.039*** (0.009) |
| Year 2021 | –0.769*** (0.225) | 0.806*** (0.237) | 0.033*** (0.010) |
| Year 2022 | –0.879*** (0.244) | 0.963*** (0.257) | –0.023** (0.011) |
| Year 2023 | –0.957*** (0.255) | 1.113*** (0.268) | –0.033*** (0.011) |
| $R^2$ (within) | 0.196 | 0.295 | 0.442 |
| Observations | 216 | 216 | 216 |
| Countries | 36 | 36 | 36 |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant.

Clustering of standard errors at the country level is necessary because the dataset is a panel with repeated observations for each country. In such contexts, the error terms will likely be correlated within countries over time (serial correlation) and may exhibit heteroskedasticity across units. If standard errors are not adjusted, the inference would be biased, leading to underestimated standard errors and overstated statistical significance. The estimates remain unbiased by clustering at the group (country) level, but the inference becomes robust to arbitrary within-country correlation and heteroskedasticity, providing more reliable significance levels (Table 4).

The results for employment in industry show that the lagged AI Vibrancy Score has a negative but statistically insignificant effect on the share of industrial employment, suggesting no robust direct relationship in the short run. GDP per capita has a positive influence on industry employment, with the coefficient being marginally significant at the 10% level ($p = 0.076$). This weakens the evidence that higher income levels are associated with a larger share of the industrial workforce. Labour force participation is negative but insignificant under clustered inference. The most consistent effects are observed in the year dummies: from 2019 onwards, the industrial employment share declines significantly, with extreme reductions during 2020–2023. This points to structural labour market shifts, likely linked to the COVID-19 pandemic and broader post-2019 global economic shocks.

In the case of employment in services, the lagged AI Vibrancy Score again exhibits no significant impact, and the same holds for GDP per capita. Labour force participation is positively associated with service sector employment, with significance at the 10% level ($p = 0.072$), implying that higher participation rates tend to reinforce the relative size of the service sector. As with the industry model, the year effects dominate: all post-2019 years display substantial and statistically significant increases in service employment shares, underscoring a reallocation of labour towards services in the wake of structural shocks.

For unemployment (transformed), neither AI vibrancy, GDP per capita, nor labour force participation show statistically significant associations. This confirms that structural variables

are less relevant in explaining unemployment variation over this short horizon. Instead, unemployment dynamics are strongly driven by year-specific shocks. Compared with the 2018 baseline, 2019 shows a modest decline, while 2020 and 2021 display sharp increases in unemployment, consistent with pandemic-induced disruptions. By 2022 and 2023, unemployment falls again, indicating labour market recovery. These results indicate that macroeconomic shocks and policy responses account for a greater proportion of unemployment fluctuations than structural variables during the studied period.

The evidence suggests that the short-term effects of AI vibrancy on employment structure and unemployment are negligible. Instead, labour market outcomes are primarily shaped by economic development (as measured by GDP per capita) and exogenous shocks (captured by year fixed effects). When robust clustered inference is applied, labour force participation plays a role in reinforcing service employment but does not significantly affect unemployment.

**Table 4.** Two-way fixed effects regressions with clustered standard errors [Source: authors' calculations in R Studio]

| Variable | Industry Employment (y1) | Services Employment (y2) | Unemployment (y3_tr) |
|---|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.223 (0.189) | –0.056 (0.166) | –0.007 (0.007) |
| GDP per capita (x2_tr) | 0.046* (0.026) | –0.034 (0.025) | –0.001 (0.001) |
| Labour force participation (x3) | –0.198 (0.168) | 0.322* (0.178) | –0.004 (0.004) |
| Year 2019 | –0.481** (0.183) | 0.511** (0.166) | –0.015*** (0.004) |
| Year 2020 | –0.592** (0.202) | 0.609*** (0.192) | 0.039*** (0.011) |
| Year 2021 | –0.769** (0.248) | 0.806*** (0.276) | 0.033*** (0.009) |
| Year 2022 | –0.879** (0.310) | 0.963*** (0.344) | –0.023** (0.010) |
| Year 2023 | –0.957*** (0.285) | 1.113*** (0.332) | –0.033*** (0.011) |
| $R^2$ (within) | 0.196 | 0.295 | 0.442 |
| Observations | 216 | 216 | 216 |
| Countries | 36 | 36 | 36 |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant.

Under the FE model (Table 6), the lagged AI Vibrancy Score shows a negative but statistically insignificant effect on industry employment (–0.22). This suggests that AI developments are not measurably reshaping industrial employment shares in the short run. In contrast, GDP per capita (square-root transformed) is positive and statistically significant at the 5% level, pointing to a tendency for more prosperous countries to maintain relatively higher industrial employment. Labour force participation has a negative and significant effect, indicating that greater overall engagement of the working-age population is associated with a smaller proportion of jobs in industry. Strong negative coefficients for 2019–2023 highlight a structural decline in industrial employment after 2019, consistent with pandemic-driven disruptions and subsequent economic restructuring.

The RE model (Table 5), by contrast, produces somewhat different results: GDP per capita becomes negative and significant (–0.020, $p < 0.05$), and the AI vibrancy effect is slightly larger in magnitude (–0.28, marginally significant at the 10% level). Including an intercept (32.8) reflects the RE model's assumption that unobserved heterogeneity is uncorrelated with regressors, which the Hausman test invalidates. These differences confirm that RE would yield misleading conclusions about the role of economic development in shaping industry employment, reinforcing the choice of FE.

The Hausman test strongly rejects the null hypothesis that the random effects estimator is consistent ($\chi^2 = 21.95$, df = 8, $p = 0.005$). This indicates that regressors are correlated with unobserved country-specific effects, meaning the random effects model would yield biased estimates. Therefore, the fixed effects (FE) specification is preferred for interpreting the relationship between AI vibrancy, GDP per capita, labour force participation, and industry employment.

The Hausman test ($\chi^2 = 31.55$, df = 8, $p < 0.001$) decisively rejects the null hypothesis that the random effects estimator is consistent. This means that regressors correlate with unobserved country-specific heterogeneity, so the FE is preferred for inference.

**Table 5.** Fixed Effects vs Random Effects estimates for industry employment (y1) [Source: authors' calculations in R Studio]

| Variable | FE Estimate | RE Estimate |
|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.223 (0.153) | –0.284 (0.154). |
| GDP per capita (x2_tr) | 0.046** (0.020) | –0.020** (0.010) |
| Labour force participation (x3) | –0.198** (0.082) | –0.078 (0.070) |
| Year 2019 | –0.481** (0.209) | –0.441** (0.216) |
| Year 2020 | –0.592*** (0.215) | –0.678*** (0.219) |
| Year 2021 | –0.769*** (0.225) | –0.595*** (0.223) |
| Year 2022 | –0.879*** (0.244) | –0.654*** (0.227) |
| Year 2023 | –0.957*** (0.255) | –0.822*** (0.238) |
| Intercept | – | 32.801*** (4.732) |
| $R^2$ (within) | 0.196 | 0.166 |
| Observations | 216 | 216 |
| Countries | 36 | 36 |
| Hausman $\chi^2$ (df=8) | 21.95 (p = 0.005) | – |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant

In the FE specification (Table 6), the lagged AI Vibrancy Score does not significantly affect service employment, suggesting no short-run measurable role of AI in shaping the relative importance of services. GDP per capita is negative but not statistically significant, implying that income levels do not systematically influence service employment once country-specific effects are controlled for. In contrast, labour force participation exerts a strong and positive effect ($p < 0.01$), indicating that higher participation rates are associated with a larger service employment share. The year dummies are consistently positive and significant after 2019, highlighting a pronounced shift toward services, particularly in 2020–2023, consistent with structural labour reallocation in the aftermath of the COVID-19 shock.

In contrast, the RE model (Table 6) produces materially different results. Here, GDP per capita is positive and highly significant ($p < 0.01$), suggesting that richer countries tend to have larger service sectors. Labour force participation remains strongly positive and significant, consistent with the findings of FE. However, the year dummies have smaller magnitudes than under FE, and AI vibrancy is again insignificant. A large, significant intercept (37.7) reflects the RE assumption that unobserved heterogeneity is uncorrelated with the regressors, an assumption rejected by the Hausman test. These results reinforce that the FE estimator is a consistent and reliable model for explaining service employment shares. They suggest that short-term AI vibrancy has no direct effect, while labour force participation and post-2019 shocks are the key drivers of service sector expansion. The comparison with RE also underlines

the risks of misspecification: RE would misleadingly attribute part of the structural increase in services to GDP per capita, whereas FE isolates the stronger role of demographic participation and global shocks.

**Table 6.** Fixed Effects vs Random Effects estimates for services employment (y2) [Source: authors' calculations in R Studio]

| Variable | FE Estimate | RE Estimate |
|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.056 (0.161) | 0.091 (0.167) |
| GDP per capita (x2_tr) | –0.034 (0.021) | 0.050*** (0.015) |
| Labour force participation (x3) | 0.322*** (0.087) | 0.328*** (0.085) |
| Year 2019 | 0.511** (0.219) | 0.417* (0.231) |
| Year 2020 | 0.609*** (0.226) | 0.793*** (0.236) |
| Year 2021 | 0.806*** (0.237) | 0.499** (0.242) |
| Year 2022 | 0.963*** (0.257) | 0.506** (0.252) |
| Year 2023 | 1.113*** (0.268) | 0.698*** (0.265) |
| Intercept | – | 37.718*** (6.078) |
| $R^2$ (within) | 0.295 | 0.302 |
| Observations | 216 | 216 |
| Countries | 36 | 36 |
| Hausman $\chi^2$ (df=8) | 31.55 (p < 0.001) | – |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant

The Hausman test (Table 7) yields a $\chi^2$ of 1.22 (df = 8, p = 0.996), providing no evidence to reject the null hypothesis that the random effects estimator is consistent. This contrasts with the results for industry and services, where FE was the preferred option. Here, the test suggests that regressors are not correlated with unobserved country-specific heterogeneity, meaning both FE and RE are valid, but RE is more efficient.

In the FE model (Table 7), none of the structural regressors, AI vibrancy, GDP per capita, or labour force participation, is a significant predictor of unemployment. Instead, year dummies drive the results: 2020 and 2021 show significant increases in unemployment, while 2022 and 2023 display significant declines relative to the baseline. This suggests that unemployment dynamics in the 2017–2023 period were primarily shaped by global shocks (most notably the COVID-19 pandemic) and subsequent recovery, rather than by long-term structural factors.

The RE model (Table 7) produces broadly consistent conclusions with slightly different emphasis. The coefficient for labour force participation is negative and statistically significant (–0.005, $p < 0.05$), suggesting that higher participation rates are associated with lower unemployment in the pooled sample. The year dummies show the same pattern as in FE: sharp increases in 2020–2021 followed by declines in 2022–2023. Importantly, AI vibrancy and GDP per capita remain insignificant, reinforcing the interpretation that unemployment fluctuations were driven more by cyclical and exogenous shocks than by structural changes in technology or income.

Given the Hausman test result, the RE model is the statistically preferred unemployment specification. FE and RE highlight that AI vibrancy had no measurable short-run effect on unemployment in this period. At the same time, labour supply factors and external shocks, notably the pandemic, were the dominant influences on labour market outcomes.

The clustered FE/RE results (Table 8) strengthen the earlier conclusion: AI vibrancy does not exert a measurable short-run effect on employment outcomes, whereas macro shocks and labour force dynamics are the dominant explanatory factors. Sectoral reallocation is evident,

with industry declining and services expanding after 2019, while unemployment patterns align closely with pandemic and post-pandemic trajectories.

**Table 7.** Fixed Effects vs Random Effects estimates for unemployment (y3, transformed) [Source: authors' calculations in R Studio]

| Variable | FE Estimate | RE Estimate |
|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.007 (0.007) | –0.008 (0.006) |
| GDP per capita (x2_tr) | –0.001 (0.001) | 0.000 (0.0003) |
| Labour force participation (x3) | –0.004 (0.004) | –0.005** (0.003) |
| Year 2019 | –0.015* (0.009) | –0.016* (0.009) |
| Year 2020 | 0.039*** (0.009) | 0.039*** (0.009) |
| Year 2021 | 0.033*** (0.010) | 0.033*** (0.009) |
| Year 2022 | –0.023** (0.011) | –0.024** (0.009) |
| Year 2023 | –0.033*** (0.011) | –0.033*** (0.010) |
| Intercept | – | 1.376*** (0.166) |
| $R^2$ (within) | 0.442 | 0.410 |
| Observations | 216 | 216 |
| Countries | 36 | 36 |
| Hausman $\chi^2$ (df=8) | 1.22 (p = 0.996) | – |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant

For industry employment, the results indicate that AI vibrancy has no statistically significant effect on the industrial share of employment in the short term, as the coefficient is negative but insignificant. GDP per capita exerts a positive effect, marginally significant at the 10% level, suggesting a tendency for higher-income countries to maintain relatively larger industrial employment shares. Labour force participation shows a negative but insignificant coefficient when clustered standard errors are applied. The most robust findings come from the year dummies. All years from 2019 to 2023 are significantly negative, indicating a systematic decline in industry employment that accelerated during and after the COVID-19 pandemic.

For service employment, the lagged AI vibrancy score again remains insignificant, reinforcing that AI vibrancy has not yet translated into measurable structural effects on sectoral labour allocation. GDP per capita also proves insignificant under clustered inference, but labour force participation is positively associated with service employment, with marginal significance ($p < 0.1$). The most pronounced effects are again observed in the time dummies: service employment rose significantly after 2019, with the most substantial increases occurring from 2020 to 2023, reflecting a structural reallocation of labour away from industry and into services during the pandemic.

For unemployment, estimated under the RE model with clustered errors, the coefficients for AI vibrancy and GDP per capita remain insignificant. However, labour force participation has a significant adverse effect, suggesting that higher participation rates may reduce unemployment in the medium term. Year effects dominate the model: unemployment fell modestly in 2019, spiked significantly in 2020 and 2021 during the height of the pandemic, and then declined in 2022 and 2023, consistent with economic recovery and stabilisation. This confirms that unemployment dynamics are primarily driven by macroeconomic shocks and recovery cycles, rather than AI vibrancy or income levels.

**Table 8.** Regression results with clustered standard errors [Source: authors' calculations in R Studio]

| Variable | Industry Employment (y1, FE) | Services Employment (y2, FE) | Unemployment (y3_tr, RE) |
|---|---|---|---|
| Lagged AI Vibrancy (x1_tr, t–1) | –0.223 (0.189) | –0.056 (0.166) | –0.008 (0.007) |
| GDP per capita (x2_tr) | 0.046* (0.026) | –0.034 (0.025) | 0.000 (0.0003) |
| Labour force participation (x3) | –0.198 (0.168) | 0.322* (0.178) | –0.005** (0.002) |
| Year 2019 | –0.481** (0.183) | 0.511** (0.166) | –0.016*** (0.004) |
| Year 2020 | –0.592*** (0.202) | 0.609*** (0.192) | 0.039*** (0.012) |
| Year 2021 | –0.769*** (0.248) | 0.806*** (0.276) | 0.033*** (0.009) |
| Year 2022 | –0.879*** (0.310) | 0.963*** (0.344) | –0.024** (0.009) |
| Year 2023 | –0.957*** (0.285) | 1.113*** (0.332) | –0.033*** (0.010) |
| Intercept | – | – | 1.376*** (0.117) |
| $R^2$ (within) | 0.196 | 0.295 | 0.410 |
| Observations | 216 | 216 | 216 |
| Countries | 36 | 36 | 36 |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant

The models estimated with AI Vibrancy in contemporaneous form (without lag) (Table 9) confirm that the index has no significant effect on labour market outcomes across industry, services, or unemployment. The Hausman test rejects random effects in favour of fixed effects for industry employment, but AI Vibrancy remains insignificant. Global shocks, rather than technological change, explain the declines observed from 2020 to 2023.

The Hausman test again supports the use of fixed effects for service employment, and AI Vibrancy shows no measurable influence. Instead, service expansion after 2019 is driven by structural reallocation during the pandemic. GDP per capita shows a marginal positive effect, while labour force participation is positive but not robustly significant. For unemployment, the Hausman test indicates that random effects are consistent. AI Vibrancy is again insignificant, while labour force participation is strongly negative, confirming that higher participation reduces unemployment. Year dummies capture the pandemic shock (2020–2021) and subsequent recovery (2022–2023). When AI Vibrancy is included without lag, it does not exert a significant short-run influence on employment structures or unemployment. Labour force participation and time-specific shocks remain the primary drivers of labour market dynamics from 2017 to 2023.

The results do not provide empirical support for the stated hypotheses that higher AI vibrancy reduces industrial employment (H1), increases service employment (H2), or raises unemployment (H3). Across all specifications, both lagged and contemporaneous, AI vibrancy coefficients remain statistically insignificant, indicating no measurable short-run impact of AI vibrancy on labour market structures or unemployment in the 36-country sample. Instead, labour force participation shows partial significance, GDP per capita exerts only marginal effects, and year dummies powerfully capture the structural shifts associated with the COVID-19 pandemic. These findings suggest that recent labour market dynamics are primarily shaped by demographic participation and global shocks. At the same time, the transformative effects of AI vibrancy are not yet detectable within the short observation window of 2017–2023.

**Table 9.** Regression results (contemporaneous AI vibrancy, clustered SEs) [Source: authors' calculations in R Studio]

| Variable | Industry Employment (y1, FE) | Services Employment (y2, FE) | Unemployment (y3_tr, RE) |
|---|---|---|---|
| AI Vibrancy (x1_tr) | –0.356 (0.223) | 0.191 (0.141) | –0.002 (0.005) |
| GDP per capita (x2_tr) | –0.015 (0.024) | 0.045* (0.024) | 0.000 (0.0003) |
| Labour force participation (x3) | –0.101 (0.198) | 0.332 (0.204) | –0.006*** (0.002) |
| Year 2018 | 0.090 (0.072) | 0.037 (0.076) | –0.024*** (0.004) |
| Year 2019 | –0.251 (0.199) | 0.409** (0.193) | –0.038*** (0.007) |
| Year 2020 | –0.486** (0.191) | 0.756*** (0.192) | 0.015 (0.013) |
| Year 2021 | –0.591** (0.274) | 0.570* (0.290) | 0.007 (0.008) |
| Year 2022 | –0.572* (0.331) | 0.567 (0.350) | –0.047*** (0.008) |
| Year 2023 | –0.726** (0.333) | 0.761** (0.354) | –0.054*** (0.009) |
| Intercept | — | — | 1.456*** (0.133) |
| $R^2$ (within) | — | — | 0.410 |
| Observations | 216 | 216 | 216 |
| Countries | 36 | 36 | 36 |

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant

The absence of significant effects of AI vibrancy on industrial employment, service employment, and unemployment can be explained by several economic factors. First, the relatively short observation period of 2017–2023 may be insufficient to capture the long-run impact of technological change, as structural transformations in labour markets typically evolve over decades rather than a few years (Acemoglu & Restrepo, 2018). During this period, employment outcomes were significantly influenced by the global COVID-19 shock, which triggered abrupt shifts in sectoral employment and unemployment, overshadowing any incremental effects of AI adoption (Adams-Prassl et al., 2020).

Moreover, the AI Vibrancy Index reflects national-level readiness and activity but does not measure sector-specific adoption. Many firms, particularly in industry, may not yet have integrated AI at a scale that would influence aggregate employment patterns. Even in economies with high AI vibrancy, adoption remains concentrated in a few firms or sectors, limiting its measurable impact at the macro level. In addition, AI deployment has tended to complement rather than substitute human labour, enhancing productivity and efficiency without leading to immediate job destruction or creation on a scale visible in employment statistics (Brynjolfsson & McAfee, 2014; Bessen, 2019).

Additionally, early-phase AI adoption tends to complement, rather than substitute for, labour, augmenting productivity rather than immediately eliminating jobs. Empirical work supports the idea that AI initially transforms tasks instead of entire occupations (Autor & Salomons, 2018). Moreover, labour market rigidities, such as stringent employment protection legislation, intense collective bargaining, and limited retraining capacities, often dampen the short-run responsiveness of employment to technological advancements. These rigidities can slow the adoption of adaptive technologies, such as AI, as firms face high costs or procedural hurdles when adjusting their workforce. A recent theoretical contribution by Fan (2025) further supports this dynamic: it shows that workers' limited mobility across occupation groups, with substitutability declining as the skill gap widens, constrains the labour market's ability to absorb rapid technological progress, even when automation begins to affect neighbouring job categories (Fan, 2025). Finally, mismatches between innovation and workforce skills slow

down diffusion: firms may develop AI capabilities without deploying them broadly enough to influence national employment patterns (Frey & Osborne, 2017).

## DISCUSSION

The empirical findings of this study suggest that AI vibrancy has not yet exerted a significant short-run effect on employment in industry, employment in services, or unemployment across the 36-country sample during 2017–2023. Instead, labour market dynamics were strongly shaped by macroeconomic shocks such as the COVID-19 pandemic and by demographic participation, with year dummies capturing sharp declines in industry employment (–0.592 in 2020; –0.957 in 2023), increases in services (0.609 in 2020; 1.113 in 2023), and temporary rises in unemployment (0.039 in 2020; 0.033 in 2021). These results diverge from early theoretical expectations that AI adoption would accelerate labour displacement and restructuring (Acemoglu & Restrepo, 2018; Autor & Salomons, 2018; Frey & Osborne, 2017), but align with more recent evidence highlighting that AI adoption often complements rather than substitutes labour in its initial stages (Bîrcă, 2025; Cramarenco et al., 2023; Bessen, 2019).

The absence of measurable short-run effects can be attributed to the aggregate and national-level nature of AI vibrancy, which may not adequately capture sector-specific adoption. This aligns with arguments that AI diffusion is concentrated in particular industries and among leading firms, thereby limiting its impact on broader labour market structures (Brynjolfsson & McAfee, 2014; Fan, 2025). Furthermore, the results support findings that labour market rigidities, institutional arrangements, and skill mismatches delay the visible impact of technological change (Istudor et al., 2024; Jarząbek & Stolarska-Szeląg, 2024; Butum & Nicolescu, 2024). The positive role of labour force participation in reducing unemployment ($\beta = –0.006$, $p < 0.01$) also echoes studies emphasising the importance of human capital and reskilling in mitigating technological shocks (Abid et al., 2024; Androniceanu, 2025; Pisică & Zaharia, 2025).

At the same time, the strong year effects in this study highlight how exogenous global crises can temporarily overshadow the influence of technological trends. Evidence from the literature confirms that the COVID-19 pandemic disrupted labour markets far more dramatically than technological change during this period, with unequal impacts across demographic groups and sectors (Adams-Prassl et al., 2020; Denissova, 2025; Trembeczki et al., 2025). The results suggest that while AI vibrancy is an important indicator of digital readiness, its measurable effects on employment structures and unemployment may only materialise in the longer run, once adoption deepens and interacts with institutional frameworks and workforce skills.

Limitations. This study has several limitations that should be acknowledged. First, the analysis is based on a relatively short time span (2017–2023), which may not fully capture the long-run effects of AI vibrancy on labour market outcomes, especially given the gradual diffusion of technological change. Second, the AI Vibrancy Score is an aggregate index at the national level and does not reflect sector-specific adoption of AI technologies, which could mask heterogeneous impacts across industries. Third, the results may be influenced by unobserved institutional and policy factors that are not explicitly modelled, such as labour market regulations, social protection systems, or targeted innovation policies. Fourth, the

findings are significantly shaped by the COVID-19 pandemic, representing an extraordinary global shock that may dominate the short-term dynamics of employment and unemployment during the observation period. Finally, the study is limited by data availability; additional controls, such as productivity, education, or technological investment indicators, could provide a more nuanced understanding of the relationship between AI vibrancy and labour market structures.

## CONCLUSIONS

This study examined whether national-level AI vibrancy exerts measurable short-run effects on labour market outcomes, specifically employment in industry, employment in services, and unemployment, across 36 countries from 2017 to 2023. The analysis sought to test the hypotheses that higher AI vibrancy reduces industrial employment, increases service employment, and raises unemployment.

The study employed panel data econometric methods, utilising annual indicators from Stanford University's Global AI Vibrancy Tool and the World Bank's World Development Indicators. After performing Box–Cox transformations to stabilise distributions, two-way fixed effects and random effects models were estimated, with the appropriate specification selected using Hausman tests. Standard errors were clustered at the country level for heteroscedasticity and serial correlation.

The empirical results provide no support for the stated hypotheses. Across all specifications, AI vibrancy coefficients remained statistically insignificant, whether included contemporaneously or with a one-year lag. In contrast, GDP per capita showed a weakly positive effect on industrial employment (estimate 0.046, $p < 0.10$) and on service employment in some specifications (0.045, $p \approx 0.06$), while labour force participation exhibited a positive association with service employment (0.322, $p < 0.10$) and a negative association with unemployment (–0.006, $p < 0.01$). The most consistent and significant results emerged for the year dummies: industrial employment declined sharply from 2020 onwards (–0.592 in 2020; –0.957 in 2023), while service employment rose (0.609 in 2020; 1.113 in 2023). Unemployment increased significantly during 2020–2021 (0.039 2020; 0.033 in 2021) before falling in 2022–2023 (–0.023; –0.033). These findings suggest that recent labour market dynamics were primarily driven by global shocks, notably the COVID-19 pandemic, and demographic participation, rather than by AI vibrancy.

## IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

Policy implications follow directly from these results. Since AI vibrancy does not yet appear to affect employment structures or unemployment in the short run, policymakers should not expect immediate labour market disruptions from AI readiness at the national level. Instead, greater attention should be paid to resilience against macroeconomic shocks, strengthening labour force participation, and supporting sectoral reallocation during crises. However, investments in workforce reskilling and AI-related competencies remain essential, as the absence of effects in 2017–2023 may reflect delayed adoption and diffusion. In the medium to

long term, the transformative potential of AI is likely to emerge, and proactive policy measures today can help smooth the adjustment, minimise displacement, and ensure that the benefits of AI are broadly shared.

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## Appendix A

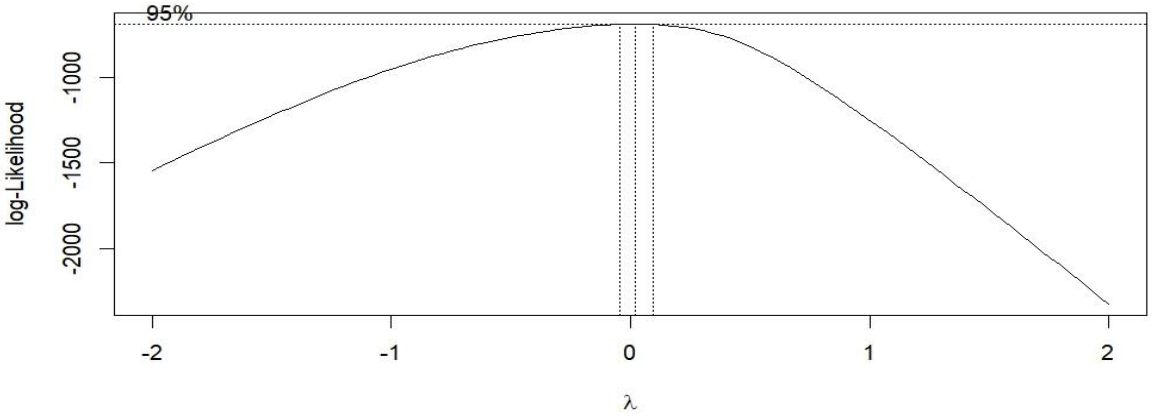


**Figure A1.** Figure A1. Box–Cox transformation plot for AI Vibrancy Score (x1)
[Source: authors' calculations in R Studio]

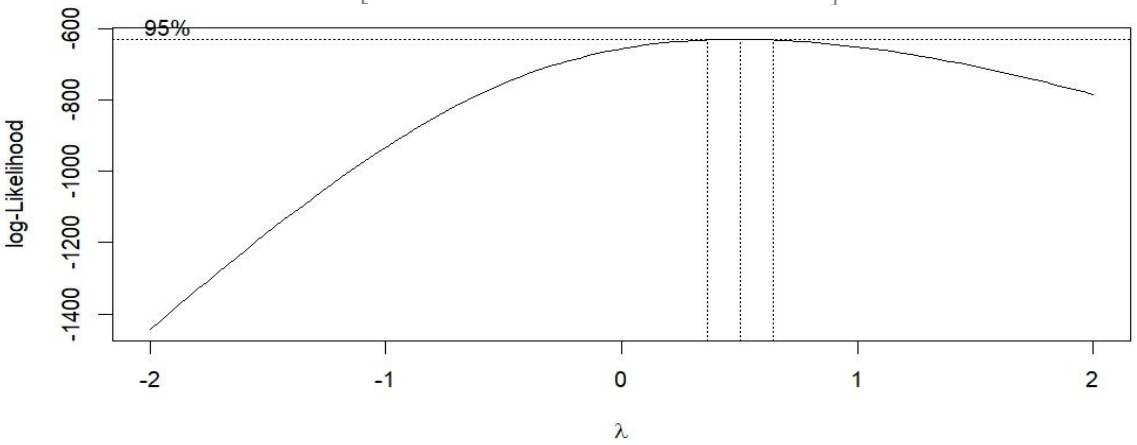


**Figure A2.** Box–Cox transformation plot for GDP per capita (x2)
[Source: authors' calculations in R Studio]

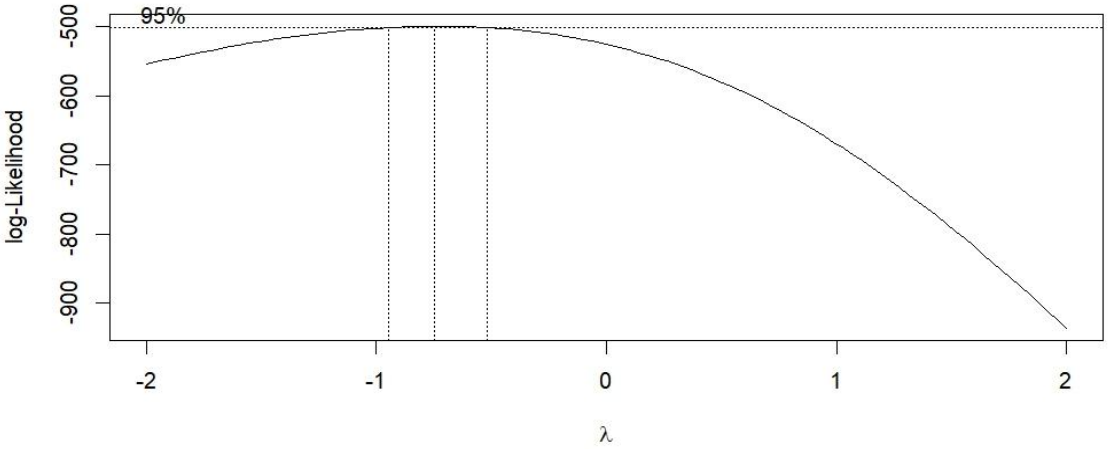


**Figure A3.** Box–Cox transformation plot for Unemployment rate (y3)
[Source: authors' calculations in R Studio]