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NEW MEDIA AND GENETIC REVOLUTION: AI IN DNA TESTING WEBSITES ANCESTRY AND MYHERITAGE

Abstract

Objectives: *The aim of this article is to show the relationship between the development of new media and genetic and genealogical research based on an analysis of the Ancestry and MyHeritage websites, taking into account their use of artificial intelligence.*

Material and methods: *In the years 2020-2025, the largest genetic and genealogy services on the global market, i.e. Ancestry and MyHeritage, were observed to make a comparative analysis of their development and use of artificial intelligence. The services were compared in terms of the services offered, such as ethnicity estimates based on DNA, genetic predispositions for inherited traits and medical conditions, the possibility of building family trees and searching for DNA "matches", as well as new possibilities using artificial intelligence.*

Results: *The results show that both services are expanding their services by incorporating AI into their offerings, especially recently, while also indicating that AI is being used, for example, to create videos. While both services have a wide range of offerings, MyHeritage has an advantage, among other things, because it uses AI to create 42 language versions of its site, as well as through its "chromosome painting" offering to compare DNA "matches."*

Conclusions: *The development of new media, coupled with the development of genetic and genealogical research, has led to the emergence of services offering customers DNA testing using artificial intelligence. These services are constantly evolving, demonstrating an effective combination of commerce and scientific research for the benefit of customers.*

Keywords: *Artificial intelligence (AI), Ancestry, DNA, genealogy, genetics, MyHeritage, new media*

Introduction

The development of the media, including the Internet and digitalization on the one hand, and genetic research on the other, have contributed to the emergence of companies offering DNA testing services, which often provide opportunities for genealogical research. Recently, the global market for this type of services has developed significantly, and millions of customers from all over the world have gained the opportunity to easily (although paid) get acquainted with their DNA, obtain information about their ethnic origin, specific genetic predispositions, or find their genetic *matches* and expand their family trees. These services are becoming more and more popular because they help people understand themselves, their identity, find their ancestors and relatives, as well

as recognize their own capabilities and shortcomings (including physiological, health or dietary problems), and thus hope to improve their lives.

The history of genetics dates back to the research of Gregor Mendel in the 19th century, but it is only in recent decades that a parallelism in the development of media and genetic research has been seen, which has led to the emergence of the websites discussed here. In the 1970s, it was built in the United States the ARPAnet network, which would later become the Internet, and in 1977 the first DNA sequencing was carried out. It was then that the foundations of the marriage of media and genetics were being laid (Sajna-Kunowsky, 2023, p. 72). In the early 1990s, the World Wide Web was born (under the leadership of Tim Berners-Lee), and in 1995 the genome of the bacterium *Haemophilus influenzae* was sequenced, as the first living organism. Dolly the sheep was cloned in 1997, and in 2000, the fly *Drosophila melanogaster*'s genome was fully sequenced. Three years later it was announced the success of the Human Genome Project, i.e. sequencing human genome, launched in October 1990. On the website of this project, run by National Human Genome Research Institute and financed by the US government, one can read: *The Human Genome Project is one of the greatest scientific feats in history* (see: https://www.genome.gov/human-genome-project).

Facebook was launched in 2004, YouTube in 2005, Twitter (today X) in 2006, while Instagram in 2010. These social media, and others, have become the most popular communication channels among younger generations. During the same period, DNA testing companies began to emerge. In 2006, a new media company called 23andMe (referring in the name, of course, to the 23 human chromosomes) was launched in the United States (California), but in 2025, it declared bankruptcy (hence it was omitted from the comparison in this study). The company MyHeritage (see: https://www.myheritage.com) was founded in 2003 in Israel, firstly for genealogical purposes, and only in 2016 it launched the offer of genetic tests. The Ancestry company (see: https://www.ancestry.com), founded even earlier, in 1996, by American Mormons from Utah interested in genealogy, entered the DNA testing market (as AncestryDNA) only in the second decade of the 21st century. The company FamilyTreeDNA from Houston, Texas, was a pioneer of Y-DNA (DNA in the paternal line, passed only from father to son, etc.) and mtDNA (mitochondrial DNA, passed down through

the maternal line) research, in contrast to the more popular autosomal DNA tests (obtained from all ancestral lines), and offered its first genetic tests in the early 21st century. In 2016, LivingDNA, founded in the UK, was launched, but other companies of this type were also born in Spain (24Genetics, tellmeGen) and other countries. All these companies have expanded their business on a global scale. This business operates in the new media industry and genetics, which, by the way, is responsible for transmitting information in nature, programming life, just as the media are responsible for transmitting information in the social *organism*, forming social life.

This marriage of media and genetics proves itself today possible thanks to the features of new media, in particular digitality. In digital media, all inputs are converted into digits. This data is then processed and stored in the form of digits and can be retrieved in this form from online sources, digital media or memory cards and then be decoded and displayed on the screen, sent via telecommunications networks or printed. In this respect, digital transmission differs significantly from analog transmission, in which all data inputs are transformed into other material objects (Lister et al., 2009, p. 25). Digitality, as one of the basic features of new media, allowed the creation of websites offering the DNA testing (based on the DNA structure composed of symbols like digits and letters). Therefore, linking the development of media with the progress of genetic research or, in other words, the new media revolution with the genetic revolution, become a fact (Sajna-Kunowsky, 2023, p. 74).

All of the above-mentioned websites allow customers who create accounts there and send saliva for DNA testing (using vials with instructions sent by these companies) to be able to easily, pleasantly navigate to a given website when, after some time, they receive an e-mail that the DNA test results are available. Although the entire process is supervised by experts in genetics and computer science, it would not be possible thanks to the use of artificial intelligence (AI). It is AI that enables quick data analysis and processing for customers, using appropriate algorithms. Due to the growing number of customers, databases are also growing, which in turn gives more and more accurate results. Therefore, it seems important to examine the functionality of these websites, which are largely based on AI that fits into contemporary research on this phenomenon, which raises hopes and fears at the same time.

Method of research

However, only two websites, Ancestry and MyHeritage, were selected for this study, given their dominance in the market, as they are the only ones offering not only advanced genetic testing but also related genealogical research. In order to examine their functionality in terms of the use of AI, the author of the study created accounts in each of them and obtained the results, which he then analyzed and compared to the results obtained by other users (relatives and others) who agreed to share them. A total of 12 DNA tests were thoroughly reviewed, in addition to superficially reviewing hundreds of other user tests as available DNA matches. This review was necessary to check whether the results on various websites are to some extent similar or different and adequate to reality, according to the general knowledge (about genetics, migration history, genealogy, etc.) and specific knowledge of users (about their own origins, traits, predispositions, etc.). Importantly, these observations have been going on for five years (in the period 2020-2025), which allowed to observe the evolution in the functioning of the websites.

After conducting the preliminary research, a comparative analysis was performed to answer the following questions:

1. How is AI used to indicate ethnicity on selected websites and which website offers higher quality results?
2. How is AI used in selected websites to demonstrate the traits and genetic predispositions of customers, and which website offers higher quality results?
3. How is AI used in selected websites to search for DNA matches among customers and which website offers higher quality in this area?
4. How is AI used in selected websites for genealogical research and creating family trees, and which website offers higher quality in this area?
5. What other possibilities using AI do selected websites offer and which offer is the most developed and potentially attractive to customers?

If the above questions refer to the *higher quality* of results, both the way of presenting the results (e.g. visually attractive maps and comprehensive explanations, charts, etc.) and the accuracy of the results (in cases where it is

verifiable and comparable to the actual state or results from other websites) were taken into account. The comparison criteria for each of the above questions can be found in the results. Ultimately, after a comparative analysis, the better website in terms of the use of AI was identified. The comparative analysis was based on an objective assessment. The author is not affiliated with any of the companies under study, so there is no conflict of interest.

Artificial intelligence as a subject of research

Artificial intelligence is defined as *a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation* (Haenlein, Kaplan, 2019). However, the phenomenon itself goes back far, although in the modern sense we should go back to the works of Alan Turing and conference in Dartmouth College in 1956, where the term *Artificial Intelligence* was coined and defined by John McCarthy as *the science and engineering of making intelligent machines* (Collins et al., 2021), although this definition has evolved and today there is no consensus on this matter, which is an increasingly discussed problem of global importance. Various aspects of AI in a historical-futurological perspective appeared in the book *Machines Who Thinks* (McCorduck, 2004).

Artificial intelligence has become the topic of many scientific publications in the last decade, touching on many different aspects of reality. For example, in relation to the issue of branding, there has been a significant and systematic increase in researchers' interest in AI over the last ten years (Truong Thi Hue & Ta Huy Hung, 2025). There are also recent scientific publications devoted to the use of AI in education (Tuczyński, 2024), medicine (Elgebaly et al., 2025), agriculture (Affonso et al., 2025), marketing (Wiśniewska & Matysik, 2024) as well as in media education (Ivaniceva Daou, 2025) and other areas of research, showing, among others, a significant increase in publications on AI in various disciplines. The use of AI in science and science education has also become the subject of research, because the *impact of AI on scientific practices is vast and changing fast* (Erduran & Levrini, 2024).

One important aspect of the problem is ethics in AI management, because *with the application of AI products ranging from daily life to more sensitive*

arenas such as military and governance contexts, there is growing concern over its ethical implications (Jiongyi Cao & Tianguang Meng, 2025). Another topic discussed in AI research is natural language processing (NLP), e.g. *to enhance video summarization by leveraging associated textual data such as subtitles, titles, and descriptions* (Alqurni et al., 2025). One of the latest publications presents the results of a comparative analysis in 12 countries, showing global news media coverage of AI (Ittefaq et al., 2025). Another topic is AI-powered digital transformation from the organizational perspective (Chrzanowska et al., 2024) and *how AI technology and media operation converge* with the assumption of "a constant change in AI media operation with direct impact on decision making, human perception or social structures (Feher, 2024).

Scientific publications linking the AI with the development of new media (Hassan, 2021), including social media (Saheb, 2024), as well as genetic research (Zhou et al., 2025; Deng et al. 2025) are also increasingly appearing. When it comes to research on the use of AI in the case of websites offering genetic tests, which is the subject of this article, there is a lack of such publications, although one study used machine learning to analyze news framing about these tests (Dobmeier, 2023).

Taking into account the popularity of the term *artificial intelligence* in the public sphere, as well as the growing importance of AI in various spheres of human life, we should expect a further increase in research and scientific publications on this topic in the near future, but the growth will not be linear, but definitely exponential.

Comparative analysis of the selected websites

The analyzed websites use artificial intelligence to estimate the ethnic origin of their customers, based on autosomal DNA. The results are presented on maps with the areas (marked with different colors) where a given person's ancestors come from. Due to the constantly expanding databases resulting from the rapid growth of users, the results are becoming more and more reliable and consistent, although these companies have different reference groups (partially overlapping, because many customers use different websites) and different algorithms. Moreover, there are differences in the division into ethnic

groups, although companies are trying to update data and create increasingly narrow, precise groups. Here we can already see the differences, however both Ancestry and MyHeritage have updated the data several times in the last five years. There is a difference in the level of detail of the data. Ancestry not only indicates ethnic groups, but in the case of the largest of them, it also indicates the regions of a given country where their ancestors come from. MyHeritage, however, offers *genetic groups*, combining different ethnic groups as a result of migration and genetic mixture. These groups are provided with appropriate descriptions. The maps of the MyHeritage and Ancestry websites are interactive, and after clicking on a given element (e.g. a region of a country), the customer receives a number of information, connections and explanations.

Ancestry offers *chromosome painting* charts, which show which segments of a given person's chromosomes contain certain ethnic groups inherited from their ancestors. The problem, however, is that these websites use different methods of analysis, based on different segment sizes, which causes problems with the consistency of results between these websites. Ancestry has recently even tried to separate the customer's origin to indicate which ethnic groups come from one and the other parent (without analyzing their genes), but without specifying whether it comes from the mother or the father. The results are also shown in the *chromosome painting* chart. Recently, MyHeritage has introduced the *ancient roots* option for registered users, indicating genetic connections with cultures or civilizations of various eras of human history, based on archaeological discoveries.

To summarize the activities of websites that use AI to estimate ethnic origin, Ancestry and MyHeritage offer equally high quality in this area, because both are constantly developing in this field, offering new analyses. In addition to analysis with interactive maps and explanations, Ancestry offers regional analysis and *chromosome painting* (divided into inheritance from parents), while MyHeritage has introduced *genetic groups* and *ancient roots*, which gives an in-depth look at the origin of a given client.

AI is also used to examine customer traits and predispositions. As in the case of ethnic origin, the companies use known results of genetic research (showing correlations between genes and traits), as well as their own databases and reference groups. MyHeritage only offers medical reports: *Genetic Risk*

Reports and *Carrier Status Reports*. In total, the client can learn about the risk of developing 22 diseases (from late Alzheimer's disease to heart or celiac diseases) and find out whether he or she is a carrier of any of the 27 diseases (including cystic fibrosis, various cancers, galactosemia and others). In each case, extensive explanations about the disease, pathogenic variants, risk factors, as well as references to scientific works regarding the issue are presented. Ancestry, on the other hand, offers genetic analysis of a number of traits, divided into several categories: personality (e.g. introvert or extrovert, morning or night person, remembering dreams, etc.), nutrients (levels of vitamins, omega-3), performance (athletic ability, hand-eye coordination, performing choreography and many others), sensory (alcohol flush, motion sickness, caffeine intake, etc.), and appearance (hair type, eye color, skin pigmentation, etc.). New traits appear from time to time (currently 83). In each case, illustrations and charts are presented showing the level of probability of occurrence of a given trait along with a description, an explanation of the importance of genetics for a given trait, and references.

After comparing the websites, Ancestry should be considered better in terms of using AI to identify traits and genetic predispositions, offering a lot of analysis. However, in the medical field, MyHeritage is the leader, focusing on genetic predispositions and carrier status for specific diseases. For many customers, this may be the most important thing.

AI is also used to search for *matches*, or genetic similarities, by identifying common DNA segments among users of the analyzed services. In this respect, both the number of found connections (although a large proportion of them, mostly small segments of DNA, are false matches resulting from chance rather than common ancestors) and the quality of presentation of these connections are important. When it comes to the number of matches, the most important thing is the size of the databases. The more users, the more potential connections, although this number also depends on the case (some genetic groups are more represented, others less, some ethnic groups lived in relative isolation, others mixed, etc.). Nevertheless, a given person can see the differences in the services on their own example. The MyHeritage and Ancestry databases are the largest in the global market, so you can find the most matches there. When it comes to the quality of the presentation of relationships, both services

offer the possibility of viewing the data of a potential relative (made available with his or her consent, sometimes partially hidden), such as name and surname (or nickname), nationality, common relatives, potential relationship, and also enable contact with that person. Both MyHeritage and Ancestry also search for common ancestors' surnames (or common ancestors, if found in family trees) and places of birth. The services also show the number of common DNA segments and their size in centimorgans (cM, a unit for measuring genetic linkage). Ancestry offers additional paid *Pro Tools*, but MyHeritage offers a *chromosome painter*, which shows exactly where on a given chromosome such a connection occurs. This is very useful in triangulation analysis and discovering which ancestors particular DNA segments come from. Ancestry has still not launched *chromosome painter* for this purpose, which is a disadvantage of this service, although the plus side is that it shows the ethnicity of a potential relative. To sum up, MyHeritage offers a little bit better match search capabilities due to the quality of the presentation of relationships, including use of the important *chromosome painter* tool.

Comparing matches to find common ancestors and relatives is more effective when users create large family trees on these websites. In this respect, the best options in the global market are definitely MyHeritage and Ancestry, i.e. services that have the largest genealogical databases and easy-to-use tools for building family trees. For this purpose, of course, they use AI, which not only automatically searches for similarities, but also suggests new people for the tree, drawing from their huge databases (including trees of other users). Both services have millions of records and are constantly expanding their huge databases. AI is used, among other things, to search them. Some of the user trees on these sites are made up of thousands of people. Equally high quality.

AI is also used by the analyzed websites for other purposes. For example, MyHeritage uses AI to translate the interface and site resources into 42 languages. Ancestry currently only has 6 language versions. Both Ancestry and MyHeritage have introduced new AI tools for photo editing and creating videos related to a customer's genealogy. Ancestry's *Memories* tab provides tools not only for creating and organizing galleries, but also for enhancing and colorizing photos, recognizing ancestors from old photos, searching in photo databases, but also creating *stories*, *documents* or *generational Photolines*.

MyHeritage also provides tools for working with photos under the *Photos* tab, including tagging people in photos, as well as colorizing, enhancing or animate photos. It also offers an AI-based *DeepStory* tool, which lets you *bring to life* a photo of an ancestor who tells a story about his/her life based on the data you have saved. Another MyHeritage's new tool is *AI Time Machine*, which is described as follows: *a fun feature on MyHeritage that uses Artificial Intelligence (AI) to create imaginary AI avatars (images) of a person as he or she may have looked in different periods in history. It takes real photos of a subject that you upload, and transforms them into stunning, hyper-realistic AI avatars depicting that person featured in a variety of themes from across the globe – from prehistoric times to the age of space exploration and beyond. Using AI Time Machine™, you can see yourself as an Egyptian pharaoh, a medieval knight, a 19th-century lord or lady, an astronaut, and much more, in just a few clicks!* (see: https://www.myheritage.com/ai-time-machine/). AI-generated videos of talking figures from ancient civilizations were also used in the MyHeritage *Ancient Origins* reports mentioned earlier. There is no doubt that the current market leader in introducing new tools using AI is MyHeritage, which is best at detecting current trends in this field.

Conclusions

The development of media and AI, coupled with the development of genetic research, has led to the emergence of websites offering services that allow customers to better understand their DNA code and the resulting characteristics, predispositions or ethnic origin, as well as to search for new relatives and ancestors, and to build large family trees. The market for this type of services has seen the emergence of companies competing today, among others, in the use of AI. The comparative analysis of the world's market leaders, Ancestry and MyHeritage, shows that both services offer high quality in ethnicity origin analysis and family tree building. The difference is in the approach to genetic predisposition testing (Ancestry examines traits, MyHeritage focuses on medical issues). MyHeritage's advantage is in the *chromosome painting* in comparing matches and in offering a choice of one of 42 language versions, which makes it truly global. However, both companies are implementing further services using AI,

offering not only the development of DNA or genealogy research, but also providing entertainment tools for creating photos, videos and other forms of multimedia that are winning AI lovers today. There is no doubt that this is a good way to expand the customer base, and AI (used by these companies before this concept became popular in the public space) is now being implemented in a conscious way in order to better sell these services, based on scientific foundations. Science and commerce go hand in hand here.

References

Affonso, F., Andrade, G., Tommaselli, F., Capezzuto, G., Gasparino, M. V., Chowdhary, G., & Becker, M. (2025). *CROW: A self-supervised crop row navigation algorithm for agricultural fields. Journal of Intelligent & Robotic Systems*, 111, 28. https://doi.org/10.1007/s10846-025-02219-2

Alqurni, J. S., Alsmadi, M. K., Alfagham, H., Alzoubi, S., Ihab, S., Sameh, A., AbdElminaam, D. S., & Khalaf, O. I. (2025). *Streamlining video summarization with NLP: Techniques, implementation, and future direction. SN Computer Science*, 6, 110. https://doi.org/10.1007/s42979-024-03591-w

Chrzanowska, E., Chrzanowski, M., & Zawada, P. (2024). *AI-powered digital transformation: Organizational perspective. Literature review. Journal of Modern Science*, 60(6). https://doi.org/10.13166/jms/197019

Collins, C., Dennehy, D., Conboy, K., & Mikalef, P. (2021). *Artificial intelligence in information systems research: A systematic literature review and research agenda. International Journal of Information Management*, 60, October 2021. https://doi.org/10.1016/j.ijinfomgt.2021.102383

Deng, J., Wei, L., Chen, Y., Li, X., Zhang, H., Wei, X., Feng, X., Qiu, X., Liang, B., & Zhang, J. (2025). *Identification of benzo(a)pyrene-related toxicological targets and their role in chronic obstructive pulmonary disease pathogenesis: A comprehensive bioinformatics and machine learning approach. BMC Pharmacology and Toxicology*, 26, 33. https://doi.org/10.1186/s40360-025-00842-1

Dobmeier, C. M., Ophir, Y., Walter, D., & Hubner, A. Y. (2023). *Mapping the media genome: An unsupervised machine learning analysis of news framing of direct-to-consumer genetic testing kits. Mass Communication and Society*, 27(6). https://doi.org/10.1080/15205436.2023.2240314

Elgebaly, A., Imam, M. A., Zumla, A., Kolvekar, S., Ahmed, R., & Zumla, A. (2025). *Transforming the NHS through AI-driven solutions: A new era of digital health. Postgraduate Medical Journal*. https://doi.org/10.1093/postmj/qgaf023

Erduran, S., & Levrini, O. (2024). *The impact of artificial intelligence on scientific practices: An emergent area of research for science education. International Journal of Science Education*, 46(18). https://doi.org/10.1080/09500693.2024.2306604

Feher, K. (2024). *Exploring AI media: Definitions, conceptual model, research agenda. Journal of Media Business Studies*, 21(4). https://doi.org/10.1080/16522354.2024.2340419

Haenlein, M., & Kaplan, A. (2019). *A brief history of artificial intelligence: On the past, present, and future of artificial intelligence. California Management Review*, 61(4). https://doi.org/10.1177/0008125619864925

Hassan, A. (2021). The usage of artificial intelligence in new media. In A. M. Musleh Al-Sartawi, A. Razzaque, & M. M. Kamal (Eds.), *Artificial intelligence systems and the Internet of Things in the digital era: EAMMIS 2021* (Vol. 239, pp. ?). Springer. https://doi.org/10.1007/978-3-030-77246-8_23

Ittefaq, M., Zain, A., Arif, R., Ala-Uddin, M., Ahmad, T., & Iqbal, A. (2025). *Global news media coverage of artificial intelligence (AI): A comparative analysis of frames, sentiments, and trends across 12 countries*. *Telematics and Informatics*, 96, January 2025. https://doi.org/10.1016/j.tele.2024.102223

Ivaniceva Daou, M. (2025). *Reimagining filmmaking education in Saudi Arabia through the use of AI*. In N. Azoury & G. Yahchouchi (Eds.), AI in the Middle East for growth and business (pp. ?). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-75589-7_15

Cao, J., & Meng, T. (2025). *Ethics and governance of artificial intelligence in digital China: Evidence from online survey and social media data*. *Chinese Journal of Sociology*. https://doi.org/10.1177/2057150X241313085

Lister, M., Dovey, J., Giddings, S., Grant, I., & Kelly, K. (2009). *Nowe media. Wprowadzenie*. Wydawnictwo Uniwersytetu Jagiellońskiego.

McCorduck, P. (2004). *Machines who think: A personal inquiry into the history and prospects of artificial intelligence*. Taylor & Francis Group.

MyHeritage. (n.d.). *AI Time Machine*. https://www.myheritage.com/ai-time-machine/

National Human Genome Research Institute. (2025, February 19). *The Human Genome Project*. https://www.genome.gov/human-genome-project

Saheb, T., Sidaoui, M., & Schmarzo, B. (2024). *Convergence of artificial intelligence with social media: A bibliometric & qualitative analysis*. *Telematics and Informatics Reports*, 14. https://doi.org/10.1016/j.teler.2024.100146

Sajna-Kunowsky, R. (2023). *Nowe media a rewolucja genetyczna*. In M. Nowina-Konopka, W. Świerczyńska-Głownia, & A. Hess (Eds.), *Nowa rewolucja komunikacyjna*. Wydawnictwo Uniwersytetu Jagiellońskiego.

Truong Thi Hue, & Ta Huy Hung. (2025). *Impact of artificial intelligence on branding: A bibliometric review and future research directions*. *Humanities and Social Sciences Communications*, 12, 209. https://doi.org/10.1057/s41599-025-04488-6

Tuczyński, K. (2024). *The use of artificial intelligence in distance education*. *Journal of Modern Science*, 60(6). https://doi.org/10.13166/jms/197010

Wiśniewska, J., & Matysik, S. (2024). *The application of OpenAI technology in marketing activities: A systematic literature review*. *Journal of Modern Science*, 60(6). https://doi.org/10.13166/jms/197016

Zhou, N., Yan, J., Xiong, M., & Zhu, S. (2025). *Decoding the heterogeneous subpopulations of glioblastoma for prognostic stratification and uncovering the promalignant role of PSMC2*. *Scientific Reports*, 15, 5714. https://doi.org/10.1038/s41598-024-83571-5