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# Digital Scientist 2035—An Outlook on Innovation and Education

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With the advent of the fourth industrial revolution accompanied by the Internet of Things, the implementation of smart technologies and digitalization already had a great impact in our society, especially when considering exponential innovation and human development. In this context, some types of employment have already been replaced or have been enhanced by the use of robots, human-machines interfaces and Artificial Intelligence systems. And there is likely more to come. If innovation can be viewed as a direct or indirect outcome of scientific research, which role will a scientist play in 2035? We developed a survey to investigate the opinions of scientists with respect to the possible future implementation of disruptive technologies, their feelings and approaches to digitalization, and particularly the impact of digital transformation on scientific education. In a futuristic scenario, we can imagine that scientists will be supported by technologies, carrying out numerous experiments, managing big datasets, producing accurate results, increasing communication, openness and collaboration among the worldwide scientific community, where ethics, regulations and social norms will always be observed. The new era of Digital Science is coming, in which humans will start to incorporate more disruptive and advanced technologies into their daily life; essential aspects for exponential innovation and development.

**Keywords: scientist, Industry 4.0, digital science, exponential technologies, digitalization, society, digital education, ethics**

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## INTRODUCTION

A scientist is an individual whose role is to conduct and document scientific research to extend knowledge in a specific area of interest. Throughout history the role of scientists evolved considerably. Scientists belonging to different epochs changed their status facing different norms and ethical values. Nowadays, scientists assume relevant roles when taking social decisions in advising policymakers and stakeholders towards a human-centered society (Ramirez and Cayón-Peña, 2016). Therefore, scientists share the responsibility to enhance cross-cultural connections and the transfer of knowledge among scientific disciplines, in which the support of smart technologies, innovation and human development underwent rapid changes. Thus, with the advent of the fourth industrial revolution, large-scale machine-to-machine (M2M) communication and the internet of things (IoT) have been integrated leading to increased automated processes improving communication, self-monitoring and production through the capability of smart technologies to analyze and solve issues without human intervention (Moore, 2020).

It would likely be predictable that in a few years, with the progressive implementation of smart technologies, usual jobs such as costumer service executives, bookkeeping and data entry, receptionists, proofreading, manufacturing, retail services, courier services, taxi or bus drivers and market research analysts will be replaced or enhanced by using robots, machine learning (ML) and artificial intelligence (AI) systems (Muriuki, 2021). In this view, we can think of science as crucial in leading this development (Schmidt and Junker, 2016), where scientists will adapt their practice through the integration of interfaces, digital platforms and innovative technologies. With that we can expect that by 2035 scientists will leave their physical laboratories and move to virtual labs, letting smart technologies conduct experiments and compute rapid analysis on big datasets within a relative short time; a scenario that would be unimaginable by relying solely on human capabilities and the current scientific education. We will need to think about scientists as performing different and more futuristic tasks by monitoring AI technologies, evaluating the outcome of analysis and by reporting in a faster and probably, more accurate way, results easily shared in real-time among the worldwide scientific community; a perspective that would necessary require a shift toward the integration of digital and technological training in the scientific education.

This concept idea of "futuristic science" will undergo a considerable evolution leading to a quick, continuous and disruptive process of innovation. Last but not least, the implementation of smart technologies need to be placed and evaluated within a revised and defined ethical framework avoiding bias, ensuring data privacy, and allowing democratic access. When implementing smart technologies, especially in the decision-making processes or in the possible execution of experiments, ethical values, social norms and regulatory approvals should be intensively discussed, common guidelines agreed becoming an integral part of future digital science. In a world of outstanding technologies, humans will start to embrace technologies as an essential part of daily living and the building blocks for exponential innovation and development.

Although we have seen a rapid growth and usage of technologies supporting scientific procedures and methods, the way of conducting science did not undergo significant changes when compared to decades ago. The scientist plays a central role in planning and executing the experimental procedures, in analyzing and reporting results, in which technologies play a marginal role in supporting the scientists' tasks. The universally accepted scientific procedure (Schuttleworth, 2008) starts with the generation of a research hypothesis (Hartwick and Barki, 1994) followed by the definition and execution of experiments in which the hypotheses are tested, and finally concluding with data analysis leading to the scientific discussion around research results. This process aims to generate new or to confirm/disconfirm previous theories enriching the scientific literature. In this process, scientific procedures are highly organized to assure validity and reproducibility among the scientific community. This requires effort, a large set of skills, research funds, and the adoption of a long-term time perspective in the achievement of results. The scientist is in charge of the project creation and execution although the outcome of the scientific experiments—just like today—can be unpredictable due to uncontrolled or external factors misleading the results. To investigate whether the implementation of smart technologies would enhance the "nowadays" way of conducting scientific research, an analysis of the advantages and disadvantages are described below.

Advantages of the current approach to scientific research:

- The scientist, as human being, is capable of planning and conducting an experiment carrying out each task necessary of its realization;
- The scientist makes use of technologies as supportive tools during the scientific procedure (e.g., data acquisition hardware, data analysis software);
- The scientist, being in charge of the project, has the chance to improve academic, hard and life skills;
- The scientist has the opportunity to socially connect with the worldwide scientific community enhancing visibility, prestige and relevant role as scientist in the community and society.

Disadvantages:

- Experiments can take years for being completed (in some cases bringing to failures and loss of research funds);
- Data analysis procedures can take years to be completed and possible leading to imprecise or incorrect results (e.g., due to lack of physiological attention, repetition, superficial knowledge when using specific technologies);
- The scientist is overwhelmed by several tasks leading to constant stress and burnout (e.g., under time-grant pressure, or by institutions);
- Researches can be affected by biases, lack of reproducibility, imprecision and uncontrolled factors;
- Other research results make the experiments obsolete;
- The long-term perspective in the completion of researches would slow down the exponential process of innovation and development.

Moreover, the shift to Industry 4.0 (BMBF-Internetredaktion, 2016), involving high-tech strategies to promote the process of computerized manufacturing, had the goal to modify the labor market relying on the massive customization of products with a highly flexible production. This process would require more automated technologies characterized by methods of self-optimization, self-configuration, self-diagnosis, cognition and AI support of workers (Jasperneite, 2011). Four principles have been identified as integral part of Industry 4.0 (Hermann et al., 2016): interconnection (i.e., the ability of technologies and people to communicate and to connect with each other *via* IoT and Internet of People) (Bonner, 2017), information transparency (i.e., operations with comprehensive information to make highly functional decisions) (Marr, 2016), technical assistance (i.e., technological facility to assist human tasks and decisions), decentralized decisions (i.e., cyber systems make autonomous decisions) (Gronau et al., 2016). In this scenario, Industry 4.0 embraces several technologies that can be included into four major components: cybersecurity, IoT, cloud computing and cognitive computing (Eboz, 2017) leading to a dynamic of changes based on increasing networking, automation of smart devices and machines to optimize performances and to generate life changing advantages. Therefore, the shift toward a more technologically advanced digital world, characterized by exponential and disruptive technologies, would influence the global industry and several aspects of our private and social life, from how we work to how we live. This fact would definitely have a great impact on education (Gejendhiran et al., 2020), particularly the way of training and educating future scientists and the way of conducting scientific research. Knowing that, and that is the goal of future oriented planning, will highlight novel innovation approaches that we should define and work on today.

## MATERIALS AND METHODS

To investigate the opinion of scientists regarding the probabilistic implementation of technologies and digitalized procedures in their current academic work and consequently their impact on scientific education, we provided a survey among research groups and graduate programs of different faculties and research institutes at the Otto-von-Guericke University of Magdeburg, Germany (OVGU). In general, we investigated their opinion speculating on a probabilistic future while asking several questions regarding their current working situation. In particular, how they did cope with Covid-19 outbreak and the need to switch toward home-office setup, how they imagine to be the future of science in 2035, how digitalization and the adoption of smart technologies would modify ethics and regulatory procedures, whether the progressive implementation of technologies would increase the quality and quantity of experiment execution, what they think about open science principles, the possibility to increase interactions with global teams through digital meeting platforms and virtual laboratories, and lastly the effect that digital transformation would have on scientific education, and the way of training future scientists to embrace the process of digital transformation.

To collect our data, we designed a survey based on quantitative and qualitative questions in English language using GOOGLE Forms. The survey consisted of 14 questions in the form of multiple choice, checkboxes, five-point Likert scale, or short answer modalities. Thirty-eight participants took part to the survey and their responses were collected online. Survey questions and answers are listed in **Supplementary Appendices A,B** respectively (supplementary material). The survey answers were statistically analyzed based on the frequency distributions. The frequencies were computed based on the median distribution. In particular, the most frequent answers were transformed into their valid percentage.

## RESULTS

From the survey analysis, the majority of responders were female (71.1%) in the age of 18–24 (7.9%), 25–34 (73.7%), 35–50 (18.4%) years old, Ph.D. students (65.8%) and PostDoc researchers (13.2%) belonging to the faculty of Natural Sciences (39.5%), Medicine (31.6%) and Process and Systems Engineering (10.5%). Only three respondents were Principal Investigators (7.9%) and one professor (2.6%). The rest of respondents were three research assistants (7.9%) and one B.Sc./M.Sc. student (2.6%).

Some respondents affirmed that the Covid-19 outbreak was impactful (28.9%) on their research work while others affirmed that this event was neutral on their research (39.5%). Moreover, some respondents affirmed they would likely continue their research work from home-office (23.7%) while others were neutral to this possibility (26.3%).

When we asked to think ahead in 2035, imagine how the future of scientists and the way of conducting scientific research would be, the most three common answers were “Artificial Intelligence (AI) manages big datasets (i.e., several data analysis done in parallel)” (60.5%), “Global collaborations using channel-based messaging/ meeting platforms” (36.8%) and “Revised education (e.g., more digital and technological skills, interdisciplinary education)” (52.6%) (see **Figure 1**). Furthermore, the most relevant technologies that scientists would be willing to integrate in their current research work to raise innovation and to embrace the process of digitization were “Digital healthcare” (39.5%), “Artificial Intelligence (or Machine learning, deep learning)” (50%), and “Data Management/Cybersecurity” (28.9%) and “Environmental Protection and Sustainability” (28.9%) (see **Figure 2**).

The responders reported that ethics and regulatory procedures would very likely (34.2%) change due to the increasing implementation of smart technologies, such as AI, robots and avatars. Another relevant topic was related to the evaluation of experimental procedures when implementing smart technologies. They confirmed that the massive implementation of technologies would very likely (34.2%) improve the experimental procedures in terms of quality, quantity, precision, time, and replicability. And, in a world connected digitally from anywhere at any time, responders reported that they would be likely (39.5%) willing to share their research with worldwide teams through channel-based messaging/ meeting platforms to enhance global collaborations.

When speculating about a probabilistic future in which science welcomes the smart use of digital technologies toward digital transformation, responders selected “Adoption of ‘Open Science’ principles” (55.3%), “Smart laboratories (virtual and cloud-based labs, co-working facilities, DIY spaces, real-time collaborations)” (26.3%), “High precision in predicting scientific results using technologies” (26.3%) and “Big data is easy to manage” (39.5%), as the most relevant advantages of digital science (see **Figure 3**). Interestingly they think that AI technologies would unlikely (39.5%) be capable of replacing human and animal experiments, even with high simulation performances. Finally, we asked whether digitalization, and the adoption of exponential technologies would have an effect on education and the way of training future scientists. Indeed, responders affirmed that this factor is very likely (60.5%) to happen, in which digital and

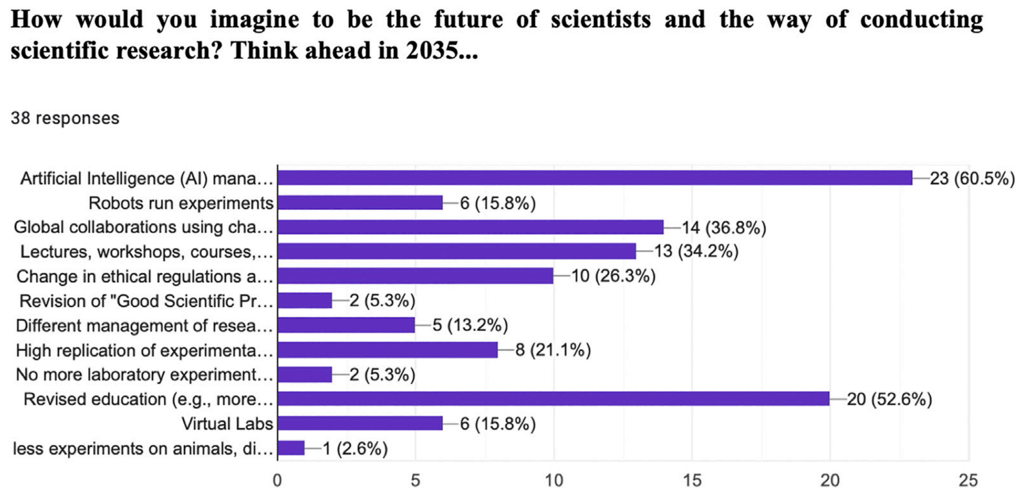


**FIGURE 1 |** Bar chart. How would you imagine to be the future of scientists and the way of conducting scientific research? Think ahead in 2035... Options were: Artificial Intelligence (AI) manages big datasets (i.e., several data analysis done in parallel), robots run experiments, global collaborations using channel-based messaging/meeting platforms, lectures, workshops, courses, and meetings happening entirely online, change in ethical regulations and regulatory approvals, revision of "Good Scientific Practice" procedures, different management of research funds/different research costs, high replication of experimental procedures among Labs (e.g., using AI, robots), no more laboratory experiments on humans/animals (i.e., ideally, precise simulations with AI), revised education (e.g., more digital and technology skills, interdisciplinary education), virtual Labs, other. The most common answers were "Artificial Intelligence (AI) manages big datasets (i.e., several data analysis done in parallel)" (60.5%), "Global collaborations using channel-based messaging/meeting platforms" (36.8%) and "Revised education (e.g., more digital and technological skills, interdisciplinary education)" (52.6%).

technological skills would be required when implementing technologies in the scientific career.

Exciting, future, fancy, promising, advances, expectantly, inevitable, optimistic, helpful, innovative, open, boost, challenge, freedom, excitement, necessary, opportunity, great chance, improvement, intriguing were the most common words that responders thought about when thinking about digital science.

## DISCUSSION

Through history and different epochs, scientists evolved enormously their social status and role facing different norms, ethical values, by advising and taking social decisions towards a human-centered society (Ramirez and Cayón-Peña, 2016). Globally connected scientists aim to transfer and share

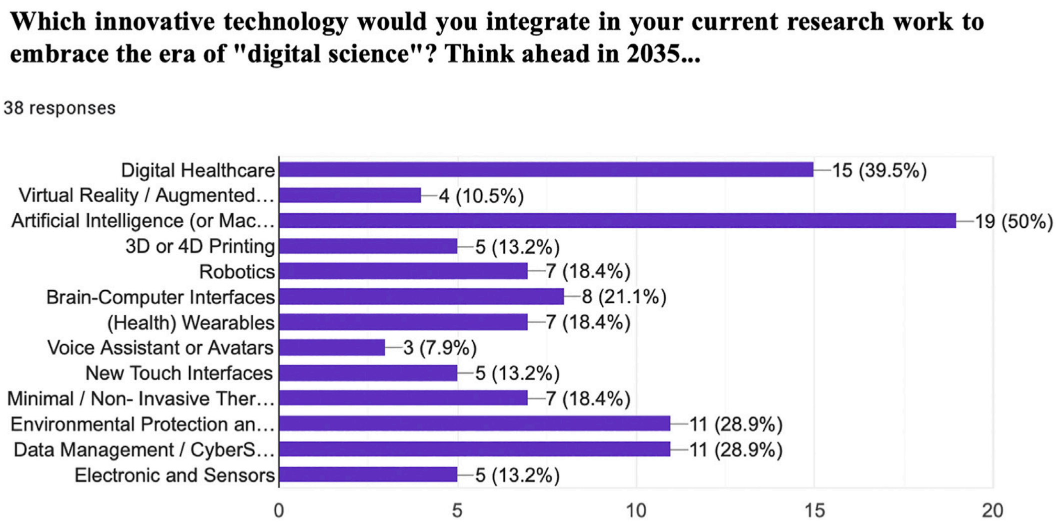


**FIGURE 2 |** Bar chart. Which innovative technology would you integrate in your current research work to embrace the era of "digital science"? Think ahead in 2035... Options were: digital healthcare, virtual reality/augmented reality, artificial intelligence (or machine learning, deep learning), 3D or 4D printing, robotics, brain-computer interfaces, (health) wearables, voice assistant or avatars, new touch interfaces, minimal non- invasive therapy systems, environmental protection and sustainability, data management/cybersecurity, electronic and sensors, other. The most relevant resulted "Digital healthcare" (39.5%), "Artificial Intelligence (or Machine learning, deep learning)" (50%), and "Data Management/Cybersecurity" (28.9%) and "Environmental Protection and Sustainability" (28.9%).

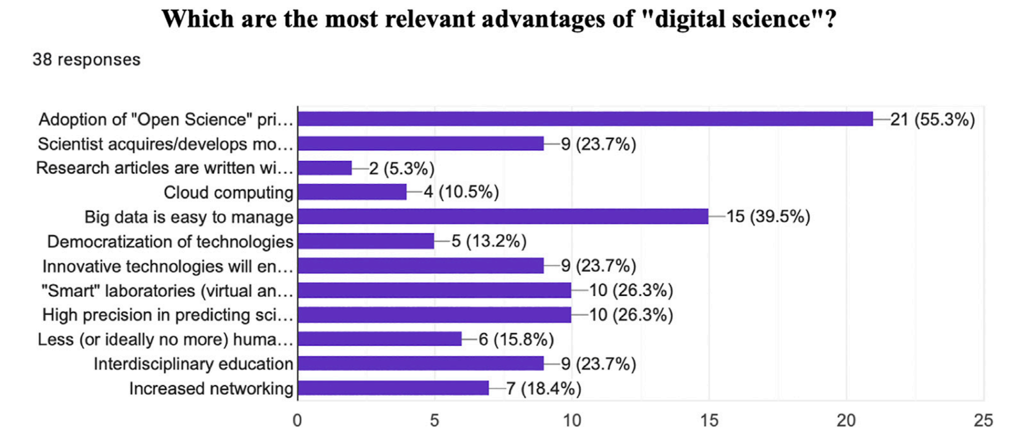


**FIGURE 3 |** Bar chart. Which are the most relevant advantages of "digital science"? Option were: adoption of "Open Science" principles, scientist acquires/develops more digital and technological skills, research articles are written with AI technologies, cloud computing, big data is easy to manage, democratization of technologies, innovative technologies will enable advanced data analysis, "Smart" laboratories (virtual and cloud-based labs, co-working facilities, DIY spaces, real-time collaborations), high precision in predicting scientific results using technologies, less (or ideally no more) human/animal experiments due to high precision simulations with AI, interdisciplinary education, increased networking. Responders selected "Adoption of 'Open Science' principles" (55.3%), "'Smart' laboratories (virtual and cloud-based labs, co-working facilities, DIY spaces, real-time collaborations)" (26.3%), "High precision in predicting scientific results using technologies" (26.3%) and "Big data is easy to manage" (39.5%), as the most relevant advantages of digital science.

scientific findings among disciplines, in which the rapid development of smart technologies led to exponential innovations and life changing advantages. Indeed, with the advent of the Industry 4.0, the implementation of M2M communication and IoT increased the automatization of processes by improving communication, self-monitoring and production due to the capability of smart technologies to analyze and solve issues without the requirement of human intervention (Moore, 2020). In this context, several jobs have been replaced by smart technologies, while others have been enhanced and thinking about scientists in their role of supporting human development, how can we imagine the evolution of scientists and the way of conducting scientific research due to the inevitable integration of technologies? To answer this question in a futuristic and probabilistic perspective, we investigated the opinion of scientists among different OVGU faculties regarding possible outcomes in the context of digitalization, digital transformation and disruptive technologies. Moreover, we aimed to extend our understanding toward the effect of these technological transformations on scientific training and education.

From our survey results, the majority of responders were Ph.D. students and PostDoc researchers from the Natural Sciences, Medicine and Process and Systems Engineering OVGU faculties. Covid-19 pandemic had an impact on our society, changing the way we were used to work toward a home-working setup. Nevertheless, this shift was not so dramatic on scientific research, as we would have expected, and responders declared that in the future they would be willing to continue their research work from remote while others were neutral to this perspective, which certainly will have an effect on needed lab and workspace.

Moreover, while thinking ahead in 2035, responders imagining to use AI systems to manage and analyze big datasets, worldwide collaborations using channel-based messaging/meeting platforms, and the inevitable integration of digital and technological skills in the curriculum toward an interdisciplinary education.

To embrace the era of digitalization and innovative technologies (OECD, 2019), responders imagine integrating digital healthcare, AI (or ML, deep learning) systems, data management/cybersecurity, environmental protection and sustainability in their research work. Moreover, responders reported that ethics and regulatory procedures would very likely change due to the increasing implementation of AI, robots and avatars but that the implementation of these smart technologies are needed while improving the experimental procedures in terms of quality, quantity, precision, time, and replicability.

Thinking ahead, in a digitally connected world, it is plausible that responders would be willing to share their research work with worldwide teams through channel-based messaging/meeting platforms and virtual/smart laboratories to enhance real-time global collaborations. Indeed, the adoption of exponential technologies and the process of digital transformations would bring indisputable advantages. Among these, the most relevant would be the adoption of "open science" principles, the acquisition of digital and technological skills, the feasible management of big data and advanced data analysis, and the possibility to predict scientific results with high precision (Börner et al., 2018). Furthermore, although the massive implementation of smart technologies, capable of supporting advanced tasks without the requirement of human intervention, high precision AI systems would unlikely be able to replace human/animal experiments due to the complexity of the human/animal being.

Finally, responders confirmed that the progressive implementation of technologies and the exponential process of digitalization, the effect on education cannot be neglected. Indeed, responders believe that this factor is likely to happen and a revised education integrating digital and technological skills would be necessary to embrace the process of digital transformation in their scientific career.

## CONCLUSION

The advent of the fourth industrial revolution accompanied by IoT, and the process of digitization brought a massive transformation in our society. Behind the process of exponential innovation and digital transformation, science and scientists are called into play. In this futuristic scenario, where smart technologies accompany our daily life, the role of scientists would undergo enormous changes. In 2035, the old image of a scientist conducting experiments and analysis in the physical laboratory will likely be heavily supported by the implementation of AI systems, where technologies would be controlled and actioned by a scientist from digital platforms and within the context of Smart laboratories.

These technologies will be in charge of managing big datasets, running unlimited analysis and producing accurate results, shared in real-time among worldwide teams. While guaranteeing good scientific practice, scientific procedures would be easily replicated, results rigorously documented, and data shared among the scientific community to stimulate openness and cooperation between global research teams enhancing the principle of open science.

Our survey was capable to investigate the opinion of scientists speculating on the possibility of conducting scientific research being supported by the wide spectrum of disruptive and innovative technologies. Although the results were optimistic and promising, in which digital science was perceived as an opportunity to improve the quality of research and the openness of research findings, which could be the consequences of this digital transformation process? Conscious that this transformation would require a revised education, scientist are willing to learn more digital and technological skills in order to fulfill an interdisciplinary curriculum while connecting with a global community through virtual platforms. Among disruptive technologies, AI systems stand out to be indispensable when approaching digital science methods, guaranteeing the management of big data, precise computations, standardization and automatization of procedures. Moreover, in this "open science" and digital scenario, the need of data management, data sharing, validation of results and data security would be a relevant topic that cannot be neglected; indeed, scientists imagine to include cybersecurity in a futuristic perspective to improve their work while adopting digital procedures. In conclusion, a novel ethical and regulatory procedures framework cannot be set aside, becoming AIs, avatars and robots integral part of our society. By promoting knowledge, avoiding misrepresentation and data falsification, by cooperating among scientists of different institutions, and by ensuring human subject protection and animal care, ethics and social norms remain essential aspects of scientific research (Resnik, 2020). Lastly, digital transformation will influence the way of training and educating scientists; digital and technological skills, as well as, interdisciplinary background will be a requirement of conducting research.

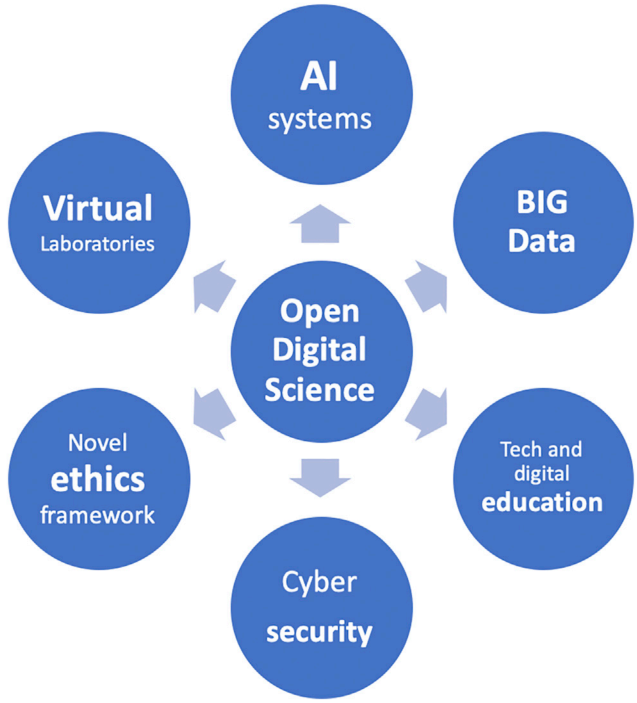


**FIGURE 4 |** Representation of open digital science factors. The actuation of digital science requires the adoption of open science principles, in which AI systems would be able to manage and analyze big datasets while guaranteeing high precision, quality, standardization of procedures and reproducibility of results. Moreover, data would be easily shared in real-time among the scientific community through virtual laboratories and channel-based messaging/meeting platforms. In this context, the need of increased cybersecurity control would be indispensable when data are shared, to guarantee the validation of results and data security. Ethics and regulatory procedures need to be revised; a novel ethical framework should be formulated when AI systems, avatars, robots and innovative technologies become an integral part of our society. Finally, technological, digital skills and an interdisciplinary scientific background would be required when training and educating future digital scientists.

In line with the four principles of interconnection, information transparency, technical assistance and decentralized decisions representing Industry 4.0, we are facing a new era that will be called as digital science (see **Figure 4**), where technologies and humans will collaborate and support each other to promote not just incremental but rather exponential innovation and development.

In conclusion, study limitations should be considered. Indeed, our small sample size might have biased the observed results. The majority of respondents belonged to similar faculties so the forecasted technologies might have been selected depending on the research field. A suggested solution would be to collect an equal number of responses among different research groups and faculties, comparing results based on each research field. We aim that further studies would consider this study limitation to improve our method for more valuable and robust conclusion.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

## AUTHOR CONTRIBUTIONS

BB carried out the experiment and contributed as first authors. BB, developed the research idea, wrote the manuscript and designed the survey with support from MF. MF stimulated the original idea and supervised the project.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomp.2021.710972/full#supplementary-material

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.