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Journal of Futures Studies
2021,Vol. 25(3) 65–78
DOI: 10.6531/JFS.202103_25(3).0006

Report

Exploring Digital Transformation in Higher Education and Research via Scenarios

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Abstract

Digital transformation induces rapid and profound changes in higher education and research (HER). With this foresight, INRAE and Agreenium, two French public HER institutions centered on food, agriculture and the environment, explore the challenges they face in a world increasingly dependent on digital resources. Four scenarios generated via morphological analysis provide researchers, teachers and institutions a heuristic framework to anticipate risks and opportunities in terms of: platformization of research, commodification of knowledge and the ascendency of data; pressing demands to respond to planet-wide emergencies; renewed multi-stakeholder relations between civil society and the academic community; and limits on energy and raw materials devoted to digital uses.

Keywords

Scenarios, Digital Transformation, Higher Education, Research, Big Data, Platforms, Environment, Multi-Actor, Frugal Use

Introduction

Digital transformation induces major changes in higher education and research. Superimposed on these ongoing changes is the sense that the mix of powerful new communication technology, big data, for-profit digital giants, citizens' new relationship with information and knowledge, and the global environmental state of affairs will yield either strikingly desirable or frightfully harmful outcomes. The perception of permanent acceleration generates both extravagant and plausible images of the future. Within this confused landscape, public higher education and research

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Received: 4 March 2020 and Accepted: 17 June 2020

institutions (referred to here as "HER") need tools to anticipate changes and develop appropriate strategies. Clarifying how HER might evolve in the face of digital transformation is complex and multi-layered. The speedy rate at which technology affects practices and organizations makes for a high level of uncertainty. The digital ramifications extending far into scientific disciplines, economic sectors and civil society generate interdependencies and non-linear changes. Divergent views regarding technology-driven or people-centered change, the role of the public sector, of civil society and of larger economic forces, as well as types of governance give rise to controversy. To anticipate the possible changes linked to digital transformation, INRAE and Agreenium, – two major French higher education and research institutes specialized in the scientific fields dealing with food, agriculture, and the environment –conducted a foresight study with a 2040 time horizon. The study focuses on the scientific and education fields dealing with these agri-food-environment domains. The changes to come, however, may be widely crosscutting and pertinent beyond the scientific domains of these two organizations. They are relevant to a range of stakeholders concerned by research, learning, knowledge sharing, the role of data in the digital economy, and the science-society relationship.

To understand the multiple processes at work behind digital transformation, we adopted a systemic approach generating four plausible and contrasted scenarios showing the possible changes lying ahead. We identified opportunities and risks associated with digital transformation in each of the four scenarios, specifying where planners and decision-makers can act. Our goal was to elicit a conversation on the implications of digital transformation in public higher education and research in a way that is both user-friendly and acknowledges multiple visions of the future.

Methodology

Bringing the people and pieces together

To engage in a foresight exercise that would create space for uncertainty, interdependencies and controversy – i.e., to convey the systemic nature of the question – we adopted a scenario approach based on morphological analysis (Zwicky, 1967; Godet, 2011) and, as much as possible, a multi-actor "future-intelligence gathering" process (Miles, Saritas, & Sokolov, 2016).

The people

Eliciting a diversity of points of views, tacit knowledge and rationales for our study meant ensuring as diverse a group of participants as possible within the boundaries of our French academic environment. We set up a working group and a project team. The twelve Working Group participants came from six academic institutions and four non-academic non-profit organizations, nine of which were French and one international. This multi-disciplinary group covered scientific expertise in agricultural, environmental and veterinary sciences, innovation studies, economics, data management, artificial intelligence, educational sciences and teaching. The project team was composed of six INRAE and Agreenium participants with expertise in foresight, human resource management learning and information technology. The combined gender ratio in these two groups was five women to 13 men. In addition, we held two focus group meetings with 44 participants from six HER institutions to help open the discussion to experts in the field of agri-food and the environment. Among participants, three had practical experience in learning design, two in human resource management, six in professional training, and 33 in teaching and research in the fields of agricultural, environmental and veterinary sciences. The combined gender ratio in the two focus groups was 25 women to 19 men.

The project team and the working group formed the central part of the project. They are authoring this paper. The project team organized working group meetings every-other-month over a period of 18 months from January 2018 to June 2019. In the course of ten full-day workshops, working group members carried out the key steps outlined below, supplied with materials prepared by the project team who also processed workshop outputs. The project team also organized two focus groups for either a full day or a half-day session. Their work is detailed below in the third step.

The pieces

The production of contrasting scenarios for the future is a way to deal with uncertainty and offer a tool for decision makers and for public debate (Johansen, 2018). The scenarios clarify the range of possible futures and helps decision makers develop strategies accordingly. To build exploratory scenarios, we adopted a scenario approach based on morphological analysis (Godet, 2011). This method explores the dynamics of complex systems while including disruptions, non-linear changes, and normative hypotheses such as goals, values and motivations (Ritchey, 2011). It is a practical tool with which a large number of hypotheses of change and their combinations can be easily visualized and manipulated (Amer, Daim, & Jetter, 2013). We conducted this study via a four-step process (Fig. 1).

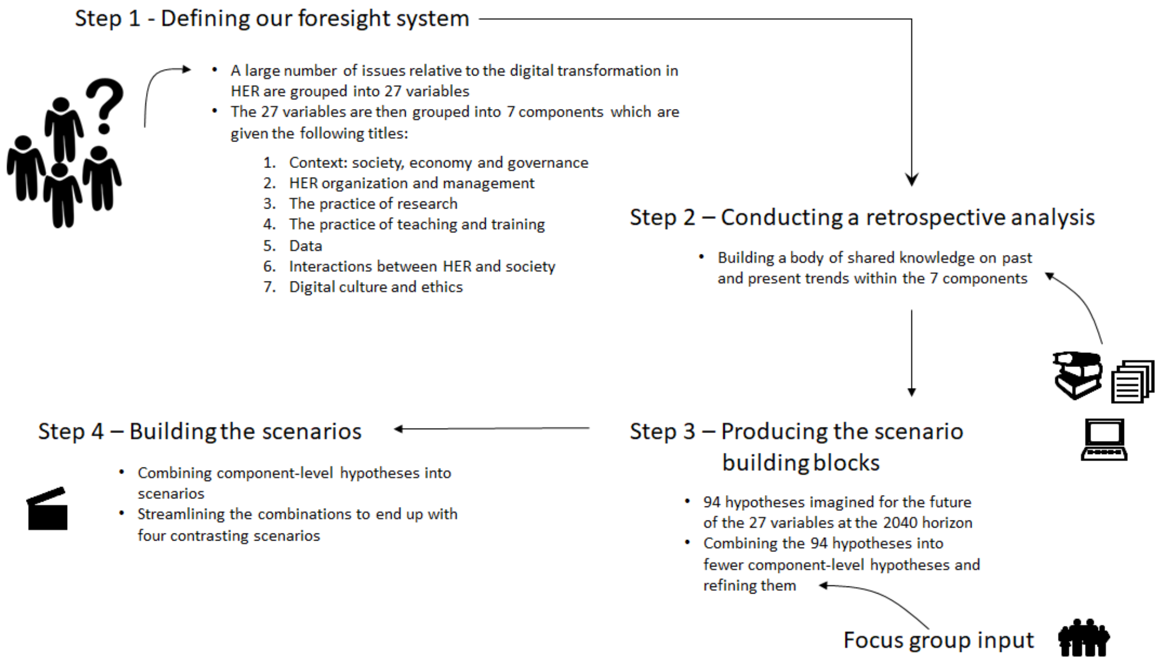

Fig. 1: The four-step process of building scenarios

In our first step, we defined our foresight system. Our working group first identified a large number of issues associated with the digital transformation in HER. We grouped the large mass of responses obtained into about 30 variables and then grouped these variables into larger "components". After ensuring completeness and eliminating redundancies and overlaps between variables, we obtained seven sets or components, each of which is described by three to five variables for a total of 27 variables overall. We gave these the following titles: (1) Context: society, economy and governance; (2) HER organization and management; (3) The practice of research; (4) The practice of teaching and training; (5) Data; (6) Interactions between HER and society; (7) Digital culture and ethics.

Our second step was to conduct a retrospective analysis and create shared knowledge on the past trends for each of the 27 variables that make up the seven components. To this end, we conducted a literature-based analysis of past and current trends, identifying weak signals and potential disruptions. We supplemented this work with three live guest lectures: on the future of education sciences, digital technology in veterinary strategies, and artificial intelligence in human learning.

In our third step, we produced the building blocks of our scenarios. For each of the 27 variables, we first formulated three to five possible changes occurring between the present time and 2040. This exercise yielded 94 hypotheses, which we combined at the component level to generate a reduced and more manageable number of aggregate hypotheses, which take the form of short narratives. We further enriched these hypotheses of change by exposing them to the critique of participants of the two focus groups. They provided their input regarding the two main components of our foresight system: "The practice of research" and "The practice of teaching and training". The high number of participants added diversity to the working group and strengthened our initial assumptions with experiences such as in-house training of researchers and teachers, classroom teaching and lab work, and with different perspectives on innovation, politics, economics and the role of civil society.

Our fourth and last step, centered on the morphological table, was to build the scenarios. For each of the seven components, the table includes three to four alternative aggregate hypotheses describing the condition or state of the component in 2040. In theory, the combinations in this matrix can describe all the future states of our system. In practice, only plausible and contrasted combinations were considered for scenario building. To lay the groundwork for future strategic action and explore what the scenarios imply for HER institutions and practices, we devoted a final one-day workshop to a collective SWOT – Strength, Weakness, Opportunity, Threat – analysis to identify opportunities and risks associated with digital transformation in each of the four scenarios.

Once streamlined to avoid overlaps and redundancies, maximize contrast and ensure coverage of a range of possible futures within our collection of narratives, we arrived at a set of four very different scenarios. In the following section, we summarize the main issues and processes identified during the retrospective analysis.

Issues and Processes Driven by Digital Transformation

In the course of this 18-month foresight exercise, we identified and formulated hypotheses while either explicitly or implicitly referring to a number of issues and processes associated with contrasting potential roles and uses of digital resources in HER. We realized that these dynamics of change, including major trends, weak signals and potential disruptions, constitute the rationale and logical backbone of the main narratives that unfolded. We present them here, grouped as four bundles of issues and processes that highlight the types of changes to anticipate analytically and separately. The scenarios, which show how those changes could interact with each other at a systems level, are presented in the subsequent section.

Big data, the epistemological controversy, and digital platforms

The future impact of big data is subject to much debate. Some see a scientific future entirely driven by data (Anderson, 2008). Digital tools and the availability of large datasets could change the entire knowledge chain. Data mining makes it possible via inductive logic to generate hypotheses or find correlations subsequently tested via a classical deductive approach (Kitchin, 2014; Kelling et al., 2009). *In silico* experiments allow the study of phenomena that could not otherwise be experimented on. Some therefore predict an epistemological break enabled by big data and machine learning algorithms where artificial intelligence could automatically generate general principles from big data (Anderson, 2008; Kelling et al., 2009). One view holds that the predictive capacity emerging from a large number of occurrences – even in the absence of understanding underlying mechanisms – would overshadow the classical process of producing knowledge by starting from theoretical principles. In its most radical form, this view predicts the "end of theory" and a shift toward an empirical and pragmatic efficiency in science (Anderson, 2008). It is not clear, however, that gaining understanding exclusively from data automatically generated and analyzed is where the future of research lies. Indeed, the latter supposes the existence of neutral data yielding neutral and robust predictions. In the new paradigm of data-driven sciences, the availability and quality of data alone would determine research orientation. Many authors, however, point to the impossibility of abstracting data from those research practices, theories and knowledge out of which they are borne (Kitchin, 2014; Vayre, 2018; Busch, 2016). Even the way the data are handled is not neutral because "how something is stored and accessed… remembered or retrieved, constitutively affects what that thing is" (Bowker, 2005). These authors accept the subjective nature of data, information and knowledge and maintain the link between the datasets and who generated them, how and why – i.e., they consider data as intrinsically "situated" (Compagnone, Lamine, & Dupré, 2018). This view may well represent a weak signal relative to the rising enthusiasm for data-driven science.

Big data is also affecting higher education. The education research community is already focusing on the specificities of educational data (Baker & Yacef, 2009). In the higher education sector, teaching staff rely on online educational platforms that provide class content and other training resources, communication tools and customized learning data. They have now acquired a central role in academia (Snijders, van der Duin, Marchau, & van Doorn, 2018). With large-scale platforms hosting Massive Open Online Courses and with the adoption of interoperability standards (e.g., Experience Application Programming Interface or xAPI), teachers and learners monitor progress with increasing accuracy. With learning dashboards based on learning analytics, learners track their own progress, teachers obtain real-time readings of student activities, and institutions compare cohorts of students going through different curricula (Campbell, DeBlois, & Oblinger, 2007). Concerns are however appearing regarding the fairness and transparency of the analyses performed and the predictions of student performance (Gardner, Brooks, & Baker, 2019).

The newly gained importance of big data and the concurrent development of science platforms could significantly transform the academic landscape. Online platforms, for sharing, storing or processing data, or for academic social networks, provide researchers with many services. Plantin, Lagoze, and Edwards (2018) describe the counter-intuitive "de-integrating" and "re-integrating" effects of web-based platforms. The de-integration comes from the breaking up of the traditional – well-integrated – academic knowledge chain and validation system by platforms and new intermediaries offering a vast diversity of products of research beyond printed peer-reviewed articles and books. The open science movement encourages researchers to share this diversity of outputs. Unfortunately, the new research products and processes are scattered and do not benefit from agreed-upon standards. There is therefore a need to re-integrate the functions carried out by the old system and there is a competition among different actors to fulfill this function. Platforms, by becoming an obligatory passage point for both research inputs and outputs, could take on this function. Although Plantin et al. (2018) focus on data, we can extrapolate the pervasiveness of platforms to all stages of knowledge production, including final reviewing and publishing (Mirowski, 2018). A few platforms could monopolize the circulation of all research products and resources. That would confer excessive brokering power to commercial entities whose interests regarding open science and scientific functions may differ from that of public academic institutions (MacKenzie, McNally, Mills, & Sharples, 2016).

Increased capacity to address complexity at the planetary level

With the multiplication of sensors, emitters, connected objects and automated pre-processing of data, the volumes and diversity of data as well as the speed with which they are produced appear to be constantly increasing. With tools and approaches such as simulation modeling, artificial intelligence and data mining, the capacity to process such big data and generate information and knowledge is also increasing. The possibility of quantum computing heightens the sense of an endless surge in computing power. It fuels the idea that digital transformation could solve the greatest present-day planetary challenges linked to climate change and other human-induced ecosystem changes. Although challenged (Colomo-Palacios, 2015; Faucheux & Nicolaï, 2011), the slogan of "IT for green" with concepts such as smart cities and smart agriculture, holds that digital technologies could significantly contribute to the ecological transition by, for example, reducing travel and the consumption of energy and physical resources while increasing collaboration and sharing.

In the scientific realm, the great capacity to handle large and diverse data, information and knowledge at an international scale confers digital resources a prime role in tackling the complexity of the environmental challenge at a worldwide scale through inter- and transdisciplinary efforts (Kelling et al., 2009; Kelling et al., 2015). The push toward achieving high levels of "FAIRness" (Findable, Accessible, Inter-operable and Reusable data) holds the promise of a great planet-wide shared use of data and the development of an integrative and transformative science. The latter, however, is dependent upon successfully addressing all four FAIR criteria including reaching high levels of interoperability (Pagano, Candela, & Castelli, 2013; Wilkinson et al., 2016). The capacity to successfully address complex inter-related global challenges appears around the corner.

Disrupting organizations and relationships

Social networks and an increased involvement of citizens in scientific debates and technological development create new and potentially tighter relationships between academia and civil society (Trench, 2008). In parallel, there is mounting recognition that efficient natural resource management must take into account the needs, knowledge and involvement of the diversity of inter-dependent stakeholders concerned (Callon, 1994). Digital resources, with their capacity to foster collaboration (Heaton, Millerand, Liu, & Crespel, 2016), offer participating individuals a privileged role in more collaborative problem solving approaches. Hacker communities at the origin of the IT revolution pioneered commons-based peer production (Kostakis, Niaros, & Giotitsas, 2014) and free and open source approaches (Broca, 2018; Kelty, 2008). They contributed to the development of citizen sciences (Strasser, Baudry, Mahr, Sanchez, & Tancoigne, 2018). These collaborative practices blur the boundaries between professional and non-professional experts and shift away from innovation conceived as initiated in academia and completed among passive users. They renew our understanding of innovation and transformative change (Joly, 2019) and contribute to adapting systems of production and consumption to ecological transition (Weber & Rohracher, 2012). But this horizontal approach challenges academic institutions in their current organization, representations and norms (OECD, 2017) and many scientists still question the ability of individual citizens and representing organizations to participate in knowledge production and HER policy (Peters, 2013; Besley & Nisbet, 2011).

Accelerated information and knowledge production, coupled with online learning communities and the flexibility and accessibility of digital technologies enable approaches where teachers and learners co-construct tools and contents. Learners become designers of their own tailored education (Allen & Seaman, 2010). Encouraged by large-scale connectivist approaches, the boundary between those who know and those who learn is blurred (Kop, 2011). The role of educators moves away from knowledge transfer toward coaching, providing advice and designing learning. Some perceive this trend as a dispossession of their classical teacher status forcing them to learn the skills required by this new relationship with learners.

The increasing power of social networks implies that academia, just as other sectors of society, will have to engage in the competition for media attention (McClain, 2017). For this, new tools and forms of visualizing results make it possible to integrate art, emotions and the human dimension in communication. New types of scientific mediators (Merson, Allen, & Hristov, 2018), intermediary activities (Steyaert, Barbier, Cerf, Levain, & Loconto, 2016), and open laboratories such as fablabs, makerspaces, hackerspaces, and *repair cafés* enable horizontal relationships between formal scientists and other potential participants in science.

An annoyance that will not go away: energy and natural resource depletion

The ecological transition requires reducing energy and resource consumption, and developing renewable energy technology. Digital technology and its uses are widely hailed as an asset in environmental protection and fighting global warming. Nevertheless, it can interfere with ecological transition and this issue is not given due attention (Ferreboeuf, 2019). The growing use of digital technology comes with an alarming growth in consumption of energy and rare metals essential to the renewable energy industry (World Bank, 2017; Halloy, 2018). The Shift Project (Ferreboeuf, 2019) reports a current energy consumption increase for production and use of servers, networks, and terminals of 9 % per year. It projects supply difficulties as early as 2030 for indium, a rare element also needed for nuclear, solar photovoltaic, and electric vehicle technologies, and warns against a "technological dead end" accompanying unbridled digital growth. Such considerations may represent a weak signal but they could one day force digital transformation to adapt itself to the requirements of the ecological transition.

Four Scenarios

Identifying hypotheses while at the same time spelling out the main issues and processes provided us with both the building blocks and the rationales with which we could construct full narratives, i.e., the scenarios. The morphological table (Fig. 2) assembles the hypotheses aggregated at the component level onto a single visual display where hypotheses are combined to potentially generate a multitude of narratives. The exercise was bounded, however, by the same criteria as those used to create the hypotheses, with internal coherence ensured by following an underlying rationale within a scenario. The goal is to produce a workable set of contrasted scenarios that reveal the widest range of HER risks and opportunities associated with digital transformation. In the end, the exercise with the morphological table yielded four bare-bones combinations, i.e., the colored pathways indicated in Fig. 2, We then converted these combinations into full-fledged scenarios: first, by providing each with a title; second, by connecting issues and processes of digital transformation and by linking them to a context coherent with their development by the year 2040; and lastly, by imagining their positive and negative consequences in particular for HER institutions in the French context. The narratives of the four resulting scenarios are presented below.

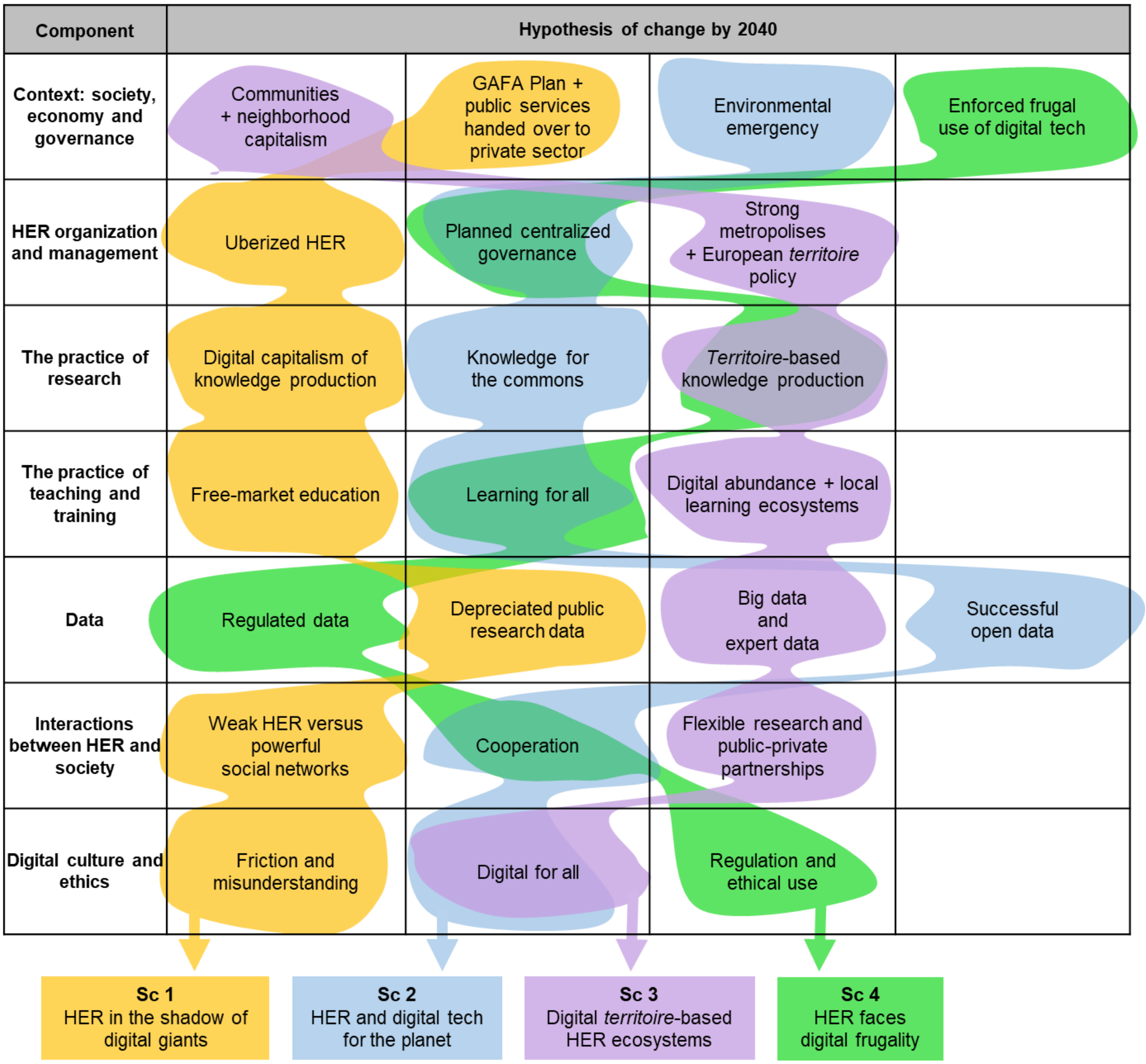

Fig. 2: Morphological table used to create the scenarios – The left-hand column shows the

seven components that make up the system. There is no intentional order either vertically (between components) or horizontally (between hypotheses). The colors indicate the combination of component hypotheses yielding the skeleton of each scenario.

Scenario 1: HER in the shadow of digital giants

With their high capacity to manage digital resources and tools, and offer services to civil society, businesses and academia, digital giants have emerged as key players in research and teaching. Since 2030, the number of researchers and teachers in HER has declined and many of them joined the private sector. From this time on, many scientists operate under self-employed status or that of company employee. The large digital firms advertise their commitment to science and innovation. Taking advantage of tax breaks on investments in higher education and research, they have developed a strong platform strategy in this sector.

In research, matchmaking and service provision platforms managed by the digital giants are now part-and-parcel of the research process. The matchmaking platforms centralize calls for proposals. Equipped with artificial intelligence, they channel public and private funding for research projects and match these with groups of researchers. They offer researchers the opportunity to form a research consortium that optimizes their chances of winning a call for proposals. It is the vagaries of funding opportunities that determine the research agenda. Service delivery platforms ensure access to data and computing power. Data-driven approaches using artificial intelligence now constitute the new standard in knowledge production in a large number of fields. In return for the service provided to the groups of researchers, the platforms automatically own the data produced. Knowledge validation also involves online platforms where artificial intelligence carries out most of the review process. Intermediation platforms evaluate researchers via an artificial intelligence multifactor scoring process that considers the number and scale of projects they are involved in, their publications and their level of funding. An ethical label completes this scoring, signaling the consideration of an ethical framework in their research. The main role of public research institutions now concerns managing the reputation of researchers, awarding labels to some and withdrawing them from others, following a branding strategy.

In higher education, two sources of learning coexist: one from the private sector covers specialized and cutting-edge topics, and one from public institutions covers more general or less sought-after topics. Public higher education persists to ensure a minimum level of training for a large swath of the population. The two-tiered system strengthens social inequalities. Teaching is a self-employed activity evaluated according to the digital reputation of lecturers as determined by online rating scores. Free educational resources are contingent on teaching platforms gaining access to the personal and learning data of students, which the former then commercially use to improve their artificial intelligence and conduct research. The main role of teachers is to coach students through their training programs, identifying and sorting the knowledge they need to access, and guiding them through the maze of online learning resources. A leading learning management system has emerged, and teachers unanimously use it through all stages of training, from defining learning goals, designing coursework and selecting digital tools, up to training of teaching teams and final evaluation. Training certification relies on open and interoperable badges attesting to the skills acquired by a student. These badges are key components within a competitive market dominated by major international universities partnering with digital giants.

Scenario 2: HER and digital tech for the planet

Since 2021, the environmental emergency engulfing the planet has gained priority status. European states are integrating this concern into their policies. The challenges of climate change, food, and nutrition security, energy consumption and increasing scarcity of natural resources are brought together under a single all-encompassing concept and translated into ambitious policies. After leading several effective and ambitious initiatives, the European Union (EU) has gained recognition as a competent actor to take up this global challenge. It has successfully established sovereignty in the digital sector by developing its own search engines, platforms, storage centers, processing tools and other digital resources. Simultaneous European regulation and coordination of national policies have facilitated a renewal in the digital sector associated with its rational use. Mobilizing digital technologies, the EU and Member States have upgraded the status of research and teaching personnel and substantially invested in public higher education and research for the development and implementation of major strategies addressing the global challenge.

Researchers, employed by national states or the EU, work in optimal conditions and conduct research focused on the preservation of the planet and on the concept of "One health" linking ecosystems and human health. National and European funding enables researchers to tackle emerging issues and conduct research aimed at improving management of the commons. The open access and open data policies of the 2020s have worked well and fostered the cooperation of a wide diversity of scientific actors, allowing the development of worldwide inter-operable databases and information systems. These resources support interdisciplinary research on global change. Digital tools mobilize the knowledge of various actors in society. Educational efforts promoting a more critical, skillful and proactive use of digital resources has contributed to maintaining trust between scientists and non-scientists. They have learned to peacefully manage digital transformation and reconcile the high speed of electronic tools and social networks with the slower pace of research. These actions have repositioned public research and its researchers at the heart of European society and the strategies required to tackle the environmental emergency.

In higher education, the coordination efforts of public authorities leads to the internationalization of curricula. Teaching is structured thematically, each theme relating to a global challenge, taking into account its interdisciplinary nature. While global challenges take on different forms locally, common situations encountered in areas situated many miles apart form the basis for multi-local higher education initiatives. Courses are mostly taught in English or translated live by artificial intelligence to meet the requirements of an international audience. Students have become highly mobile and are now building their careers by drawing from modules in a European digital catalogue that guarantees the recognition of diplomas throughout the Union. It is now possible to obtain certification by studying a topic and its geographical variations in different regions of Europe.

Scenario 3: Digital *territoire*-based HER ecosystems

Based on strong European *territoire*[1] (Barreteau et al., 2016) and regional development policies, public research and higher education are organized according to regions and metropolitan areas. To better respond to local needs, the HER national system is geographically spread across locally distributed HER hubs linked by inter-territoire networks. These research-and-innovation hubs are managed in each territoire focusing on locally defined themes.

HER hubs integrate research and higher education in close association with members of surrounding communities. They form the core of research and innovation ecosystems. Locally anchored digital platforms and open laboratories have become key elements of strong science-society cooperation. Companies located in the *territoire* become partners of the HER institutions and sit on research evaluation committees. Research teams have close relationships with their partners and promote short research-innovation cycles. Different forms of cooperation between researchers, teachers and local participants, such as local authorities, business people, professionals, representatives of consumer groups and patients have become institutionalized. Participatory science is high on the agenda. Citizen groups influence the research and education agenda by participating in local decision-making arenas. Stakeholders collaborate with researchers to launch alerts and plan research and teaching programs. *Territoire*-level digital infrastructures favor interactions between public and private actors and research. Locally connected objects and sensors generate large amounts of data that are made highly interoperable. Artificial intelligence assists researchers in their data processing work. The interdisciplinary and transdisciplinary knowledge produced drives innovation and new services benefiting local actors. The locally pertinent nature of the research does not hinder either the scaling-up of innovations, or the academic excellence of researchers who remain highly organized within networks operating at the national, European and international levels.

Citizens from civil society as a whole have now mastered the use of digital technology. They have developed a critical mind about the origin of information and this questioning translates into a more judicious use of digital technology than in past decades. Self-regulation of digital use and policies taking into account the notion of data as a common good reinforce trust between scientists and social actors – a relationship previously damaged by the proliferation of false information (i.e., fake news) in the 2020s and by the unintended appropriation of data by powerful firms. The boundaries between amateur and professional experts are blurred and there is a growing sense of complementarity between scientific and experiential knowledge. A new approach to research and teaching responding to local demands is in the making.

Teachers are employed by local government. They help students make the most out of the multitude of tools and online digital content at their disposal. Locally based fieldwork has become more important in teaching. Fundamental modules, such as statistics or mathematics, that do not require hands-on fieldwork, are offered entirely on digital platforms run by learning designers who co-construct digital tools with students. Learning communities continuously emerge. They co-produce knowledge in close connection with local actors.

Scenario 4: HER faces digital frugality

In the 2020s, states were challenged with an acute shortage of the resources needed for digital technology, excessive energy costs and considerable environmental and psychosocial impacts. The uncontrolled growing use of digital technology faced a dead end. Taking advantage of a global movement in favor of balancing digital use with environmental protection and social and behavioral health, the European Union and Member States opted to regulate digital use. Subject to the 'data-byte tax', consumers reduced the intensity of their digital practices, and the share of digital energy consumption dropped drastically. Created in Europe in 2035, this tax – modelled on the carbon tax of the 2020s – allocates individual citizens as well as private and public organizations a maximum amount of data they can use and a maximum storage and calculation space. Those with higher needs can buy data-byte rights from the European Central Digital Bank, which regulates use.

Digital frugality – initially adopted reluctantly – is well accepted thanks to public investment in research and development aiming for the advancement of an inclusive learning society. Supporting the development of frugal and alternative uses of digital technology to reduce environmental and social impacts is a priority for research, higher education and training professionals. While digital technology continues to be a mainstay in society, citizens nurture responsible uses that free them from the digital burden in terms of continuously accelerated activity, reduced attention spans, excessive multi-tasking, cognitive overload, addiction and excessive use of rating opportunities.

The research sector's main mandate is to develop frugal digital practices in society. It focuses on the co-construction of less standardized knowledge and practices that are better adapted to and rooted in local specificities. Although public researchers benefit from more ample access to digital resources, they set an example by optimizing, pooling and sharing resources, and by sharing tasks and knowledge within hybrid research communities that bring together interdisciplinary and transdisciplinary teams of professional and non-professional researchers. They revamp data science with the objective of reducing the use of digital resources. Modeling that is directly coupled with laboratory and field experimentation is favored over *in silico* modeling. Prior to launching projects relying on the use of artificial intelligence, whether simulations or any tool requiring significant digital resources, cost-benefit analyses are conducted. Research on agricultural and veterinary practices, on food system processes and on the management of natural resources seeks to design low-input resilient systems. To ensure that knowledge is adapted to local needs and contributes to saving digital resources, HER is decentralized and its geographical coverage is carefully coordinated.

Higher education is also decentralized and distributed, contributing in the same way to digital frugality. Learners acquire new knowledge and practices by confronting local realities in the field or in the laboratory, and by interacting with other actors. Learners and teachers, active in hybrid learning communities, co-construct tools and educational content online and face-to-face. Teachers now play the role of facilitators and aggregators of knowledge and know-how. They function as leaders within community groups brought together around shared objects of study that are locally relevant and transdisciplinary in nature.

What it Means to HER

To prepare for future strategic action and explore what the scenarios imply for HER, we identified opportunities and risks in each of the four scenarios using a SWOT – Strength, Weakness, Opportunity, Threat – analysis. This allowed us to define the issues HER members can address relative to the situations described in the scenarios. The main findings are presented hereafter.

HER encounters platformization of the research process and commodification of knowledge

In scenario 1, the entry of for-profit digital platform companies into research and education carries a number of risks for non-profit and public institutions. Economically powerful players providing continually improved digital tools, ever-increasing and cheap big data and an over-abundance of online learning resources might dwarf public research and education resources. The process of de-integration and subsequent re-integration driven by platforms exacerbates the risk of capture of research data. Coupled with the automation of research steps such as peer-reviewing, the knowledge chain could become vertically integrated within one or a few grand platforms (Mirowski, 2018). It could affect the balance between market-oriented motives versus interest in the commons when it comes to the research agenda and ownership of information and knowledge. It raises ethical issues regarding the use of learning and personal data. Quick-and-dirty rating habits – number of "likes" – now commonplace in the platform economy may extend to teaching and research – with either detrimental or beneficial consequences.

On the strength and opportunity side, HER institutions can rely on their comparative advantage when challenged by profit-driven goals. Indeed, most disciplines, whether in education or in research, benefit from a substantial academic heritage and established networks – assets newcomers would lack. In addition, the independence that public-sector academics enjoy may shield them from fickle economic fluctuations and thematic interests or skill fads. They may serenely develop their excellence in value-laden or niche areas outside the mass buzz.

HER capacity to respond to a planetary emergency

In scenario 2, risks and opportunities concern HER capacity to respond to a global environmental emergency. HER institutions appear equipped to take on such a challenge. To some extent, they are already operational at the international level. International research networks and infrastructures, widespread use of the English language in coursework, interactive online educational resources, and the scientific fields relevant to the global challenges at hand are well established. Nevertheless, HER institutions have not organized these assets to efficiently address highly complex planet-size problems. The challenge is a systemic one requiring a strong inter- and transdisciplinary practice that would come about via a radical transformation of the research and innovation system. It also demands an integration of multiple sources of diverse data made possible by high levels of interoperability – i.e., a thorough implementation of FAIR principles and open science. To make the most of available data and digital resources, an enabling environment is needed. Regulated, ethical and agreed upon uses of digital resources would build trust between academic users of data and producers of the needed data. Another challenge linked to tackling an emergency problem regards the handling of expectations. Faced with urgency, citizens and policy makers might demand rapid and measurable real-life results pushing HER to focus on problem-solving and action-oriented knowledge production.

A collaborative multi-stakeholder HER driven by digital transformation

Scenario 3 envisions a world where civil society and for-profit organizations engage in the entire research and innovation process and the academic community engages in local affairs. Failing to achieve such collaboration risks creating a rift between well-connected and active stakeholders and academic institutions and, more generally, a growing disaffection with public research and education. The challenge is for HER to gain a local foothold and adopt multi-stakeholder modes of research and learning based on dialogue, knowledge exchange, and problem solving. Researchers and educators can avail themselves of new uses of digital technology that facilitate two-way conversations and co-construction in interactive, user-friendly and enjoyable ways that integrate reflexivity and ethics, as well as arts and subjectivity. The development of *territoire*-based HER hubs is an opportunity to further integrate research and higher education locally and generate synergies around participatory science.

HER in a frugal digital transformation

As described in scenario 4, limits on allocating energy and other resources to digital transformation may appear detrimental to HER. Those scientific fields most reliant on large-scale data collection and use, on computer simulations, and on artificial intelligence would presumably have to adapt, with a possible revival of a more symbolic form of artificial intelligence instead of data-heavy algorithms. Redundancies in the production and use of resources would have to be eliminated. There is, however, a positive side to such constraints, in terms of the way HER functions as well as opening new areas for innovation and knowledge production. Optimizing the use of digital tools could translate into increased levels of sharing and collaboration between research and education institutions as well as between individuals. A frugal digital transformation could bring about a valuable and stronger coupling between, on the one hand, modelling, and, on the other hand, field activities, lab work and experimentation. More notably, HER contribution to the development of frugal uses of digital technology in human activities throughout society might constitute a fruitful area for innovation.

Issues cross-cutting all four scenarios

Irrespective of the scenario – even with frugal digital transformation – the enhanced computing and communication power conferred by digital technology plays a large role. In all four scenarios, big data, modeling, and artificial intelligence carry risks and opportunities for HER. Digital technology – artificial intelligence in particular – might perform many HER tasks currently undertaken by humans. The options on the horizon are multiple. In research, they include data-driven research and its "end of theory" extrapolation; algorithms driving research agendas; automated validation, exploitation and circulation of knowledge; and new modes of organization based on dynamic horizontal and individually-tailored networks. In higher education, they include changing roles of teachers, self-learning, curriculum development based on learning analytics and market opportunities, continuous certification of skills, and online learning. The specific risks and benefits associated with such transformation remain to be accurately identified.

Conclusion

This foresight study presents a set of major possible changes for HER, each encapsulated in a single plausible system in the form of a scenario. The challenge with such a systemic approach is to be broad enough to encompass the realm of possibilities thoroughly, while avoiding excessive complexity and over-abundance. That is why the morphological table, where everything can potentially interact with everything, should be used with care. We strove to balance its all-inclusive nature by the judicious use of the criteria of plausibility, coherence and pertinence within, and contrast between scenarios. In this way, we were able to manage large number of factors associated with digital transformation.

The scenarios underline how digital transformation could affect the organizational makeup, management and practices at least for HER institutions dealing with food, agriculture and the environment. Taken together, they might provide a heuristic framework to anticipate risks and opportunities for researchers, teachers and institutions, and could contribute to the debate regarding the consequences of digital transformation for public higher education and research beyond the French academic context and the disciplines represented here. At INRAE, our scenarios have already contributed to an ongoing debate resulting in the creation of a 60-staff unit devoted to open and participatory science as well as a strategy to strengthen its links to learning institutions. At Agreenium, they are used to devise a coordinated digital strategy. The real-life outcomes of digital transformation will partially depend on the stance adopted by public higher education and research institutions relative to the four major trends identified.

In the Covid-19 dominated time of finalizing this article, the implications of social distancing highlight key issues and processes discussed here. The prospects of an even more rapid and extensive reliance on digital resources in both higher education and research make the opportunities and risks identified in this foresight more pertinent. The crisis exacerbates the need to better understand the consequences of the extensive use of digital tools and the generalization and limits of teleworking among researchers, teachers and the general working population. The feasibility and equity of exclusive reliance on online courses and distance monitoring of students is now challenged. The value of scenario-based preparation plans in addition to predictive digital models is reaffirmed. The issue of trust in scientific information and the contributions of citizens to research, education and innovation is more than ever present in media debates. New uses of digital data, most recently in public health, continue to emerge and strengthen their spotlight position in research. Increased reliance on digital tools in public sector HER also sharpens the more strategic and political question regarding which actors are set to gain or lose from the expanding role of platforms and data.

Acknowledgments

This study was jointly funded by INRAE and Agreenium.

Notes

1- We employ the French word "*territoire*" as no equivalent was found in English. In French, it is used in the Social Sciences to refer to a geographical area that includes the human communities providing its economic, ecological and cultural reality. In English, "territory" pertains to a geographical area not always including the communities in it, and often refers to jurisdiction and control. "Community" refers to a group of people not always geographically-based (Antonsich, 2017).

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