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Transitioning to Bioindustry 4.0:
A Public-Private Approach to Workforce Development

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contents

introduction

Biopharmaceutical manufacturers' steady adoption of Industry 4.0 principles[1]—lean thinking, data transparency, decentralized decision-making, and interoperability of components, to name a few—is demanding new skills and mindsets of employees. Today's workforce needs expertise not only in the science of biopharmaceutical development but also in the technologies of advanced and digitalized biomanufacturing and the practices of lean management.

The challenges are considerable. In a 2021 survey of 150 leaders of biopharma companies (with $1 billionor more in revenues) in Asia, Europe, and the United States, nearly half of respondents (47 percent) said that their organizations needed the right talent to scale and accelerate digital innovations, such as bioprocessing 4.0.[2] The skill gaps of new hires and the shortage of trained workers threaten to derail the transition that biopharmaceutical companies must make now towards digitalizing and automating their operations.

In this paper, we discuss the responsibilities that academia and the biopharma sectors each have in preparing the biomanufacturing workforce of the future. Industry and educational institutions must work more closely together to develop specialized training programs that will prepare future graduates and upskill existing employees, to effectively meet the needs of industries in the transition to 4.0. These programs will include traditional scientific disciplines, digital competencies, and practical experience.

For graduates seeking jobs in biomanufacturing—biology, biochemistry, pharmacology, and industrial engineering—universities must supplement traditional education with (1) specific information technology (IT), operational technology (OT), and associated technological skills, and (2) real-world experiences through internships and other hands-on opportunities to engage with technologies graduates will encounter in the workplace.

Manufacturing companies, on their part, must commit to fostering continuous learning by providing (1) training and development opportunities for existing employees to enhance their skills, knowledge, and competencies and (2) internship opportunities for prospective employees—students and apprentices—to acquire the practical experience that is vitally important to advanced, digitally efficient manufacturing and R&D roles, and (3) insights to guide academic institutions as they seek to better prepare graduates for employment at 4.0 facilities.

We outline a collaborative, public-private approach for training the biopharmaceutical manufacturing and research and development (R&D) workforce. We provide context for this approach and present a project that implements it in France. We intend our paper to serve as a playbook for actors in the biopharma ecosystem—universities, investors, biopharmaceutical companies, and others—so they can adopt this approach in other parts of France, across Europe, and beyond.

The evolution to Biopharma 4.0 requires a workforce with new skills, new ways of thinking, and creative problem-solving capabilities.

Industry 4.0 encompasses more than digital technologies; it applies the principles of lean manufacturing, such as delivering value to customers, mapping value streams, maintaining flow in these value streams, cultivating market pull for products and services and pursuing perfection, the whole of which generates returns on investment and reduces waste and environmental harm.

Industry 4.0 in Biopharma

According to the World Economic Forum, Industry 4.0 represents a convergence of technologies that blurs the boundaries of practice among physical, digital, and biological domains.[3] Publicly introduced in 2011 at the Hannover Fair, the term (short for "Fourth Industrial Revolution") originated in a project in the high-tech strategy of the German Government.[4]

A. Digital Technologies plus Lean Thinking

In 2013, researchers in biotechnology identified the digital forces at work in their field and the key capacities that organizations would need to develop in the coming decade:

Biopharma 4.0 and its accompanying technologies—AI [artificial intelligence], ML [machine learning], the IoT [Internet of Things], advanced sensors, automation systems and capabilities for data mining and analytics—require a more diverse workforce than what the industry currently has at its disposal.

Of critical importance during the 4.0 transition are enhancements to quality control, business decision-making and operations. However, digitalization is the critical path that the biomanufacturing industry must take forward.[5]

Indeed, biopharmaceutical manufacturers that had adopted such advanced technologies before 2020 showed remarkable resilience in managing the challenges imposed by the COVID-19 pandemic.[6] In contrast, the pandemic hit laggards directly—governments included—before they could mobilize and respond innovatively.

But Industry 4.0 encompasses more than digital technologies; it applies the principles of lean manufacturing, such as delivering value to customers, mapping value streams, maintaining flow in these value streams, cultivating market pull for products and services and pursuing perfection, the whole of which generates returns on investment and reduces waste and environmental harm.[7]

Individuals who master digital tools and lean practices together will find themselves in high demand. Companies that do the same will begin sensing and responding faster to market demand and disruption.

B. The Benefits of Industry 4.0

Across industries, organizations are embracing Industry 4.0. To optimize performance and sustainability, they are transitioning from conventional factories to so-called smart manufacturing facilities. These facilities integrate such tools as AI, connectivity, sensors, model simulation, and digital learning, as well as adopting new manufacturing strategies like continuous processing.

Advances in these areas have massively increased data collection, so firms must develop systems for validating, storing, and analyzing all this information.[8] Data collection and analysis serve to improve processes, maintenance, and efficiency. Industry 4.0 confers greater output and enables products and services that effectively target customer needs.[9]

Advanced digitalization, automation, and connectivity also have the potential to alleviate risks unique to the biopharmaceutical production

industry. For example, they can help minimize human errors that result in batch failure rates and manufacturing deviations. For example, more than 300 manual interventions in an average 200 L monoclonal antibody (mAb) single-use process are prone to error.[10] Indeed, people cause an estimated 25 percent of mistakes in biopharmaceutical manufacturing.[11]

Adopting Industry 4.0 principles can help to improve regulatory compliance, batch time review, regulatory filings, and security of data collection. In a 2020 survey of the Portuguese biopharmaceutical industry, area managers and Industry 4.0 specialists alike agreed that 4.0 technologies would increase not only the quality of effort in meeting regulatory and socio-environment responsibilities but also the efficiency of performance and productivity and the generation of new models of competition.[12]

The advantages of adopting Industry 4.0 are far-reaching across sectors. At both national and organizational levels, Industry 4.0 contributes to economic resilience and competitive advantage by decentralizing industry structures, tracking and coordinating assets in real-time — increasingly, through digital twins—and decreasing complexity and related costs.[13]

Industry 4.0 pioneers also challenge such labor practices as outsourcing and offshoring talent: "Business performance undeniably depends more and more on the quality of interactions between economic players inside and outside the value chain," according to the authors of a 2020 French study of the economic and social impact of Industry 4.0.[14] Beginning in 2012, the European Commission worked to reshore manufacturing and boost its "share of GDP in Europe from 15 percent to 20 percent by 2020."

A 2023 survey of 1,250 biopharma executives across 22 countries concluded that sourcing talent was a major challenge.

C. The Challenges of Implementing Industry 4.0

Before the COVID-19 pandemic, demand for new talent in biomanufacturing was booming, growing by 26 percent between 2018 and 2020.[15] One year into the pandemic, biopharmaceutical manufacturers' demand for automation engineers, data scientists, and data engineers exceeded supply. By the end of 2021, demand had increased another 32 percent in both the United States and Europe.[16]

At the same time, the supply growth was just 10 percent, and entrants' skills did not align with the evolving needs in the sector on both continents.[17] The sector suffered from not only a skills shortage but also a pronounced supply-demand gap in the Bio-4.0 workforce. A 2023 survey of 1,250 biopharma executives across 22 countries concluded that, among the pressing issues confronting the industry, sourcing talent was a major challenge.[18] Hence, top-tier jobs remain vacant.

1. Potential Hires Are Not Prepared

While new university graduates know the latest scientific concepts, they often lack the full range of skills required to work in modern 4.0 facilities. As operations evolve, the skills expected of new hires also evolve.[19]

Adding to the crunch, biopharmaceutical companies compete for talent with many other employers in their own countries and at a global level.[20] As one observer put it, biomanufacturing 4.0 "has positioned the sector in direct competition with the technology industry" for talent.[21]

Finally, students perceive the biopharmaceutical industry to be less environmentally friendly and innovative than other high-tech sectors, which diminishes their interest in pursuing careers in "big pharma."[22]

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—Robotization and Automation Transformation Leader, Biopharma Employer[23]

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—Robotization and Automation Transformation Leader, Biopharma Employer

2. Existing Workers Are Not Prepared

In general, existing employees have the requisite industry experience and connections with their communities of practice, but they lack the skills or incentives for transitioning to Industry 4.0.[24] Workforce training lags, and the skill gaps of many current employees are glaringly evident.

In most cases, the growing use of data science, AI, machine learning, process automation and robotics will not necessarily supplant factory workers. Rather, such usage will substantially alter the characteristics of many jobs, compelling employees to master a broader array of skills than they traditionally needed.[25] Employees will have to take a multidisciplinary perspective and excel in activities like building and problem solving that computers and IT systems execute less efficiently.[26] Such efforts will benefit from the availability of accessible and appropriately targeted training courses.

3. Industry Is Not Prepared

Despite the substantial advantages that digital transformation can bring, top players across industries have hesitated to adopt it. Many biopharmaceutical manufacturers have deemed their systems, data and approaches to organization management inadequate for the transition.[27]

At a fundamental level, managers recognize that transitioning to biomanufacturing 4.0 necessitates a significant cultural shift, one that might be both expensive and disruptive to employees. At all organizational levels, staff may need to embrace entirely new work approaches, as their facilities implement state-of-the-art technologies and processes for realizing operational efficiency.[28] Reskilling and upskilling are part of the solution.

Collaborations between businesses and educational institutions are also important; they can help to dispel misconceptions about the industry and equip the workforce—whether students or mid-career professionals—for the biopharma future.

Table 1: Digital Plant Maturity Model: Moving from Level 1 to Level 5

Level 1 Pre-digital plant	Level 2 Digital islands	Level 3 Connected plant	Level 4 Predictive plant	Level 5 Adaptive plant
Primarily paper based process Predominantly manual processing Low Level of automation Basic PLC controls Applications are standalone with minimal or no integration Primarily reactive maintenance, run to failure Basic environmental manual processing of energy bills	'Islands" of automation Some manual processes Batch records mau be semi-electronic or 'paper on glass' QC labs running local systems with some level of instrument integration. Local batch-recipe system interfaced with PLCs Site-specific system; limited integartion across functional silos Analytics on demand, 'why did it happen?' high manual effort Reactive with basic scheduling and evidence of maintenance via CMMS analytics Basic environmental sustainability analysis	Vertical integration ERP, LIMS/LES, MES and automation layer are fully integarted to support digitized business process Full electronic batch record with review by exception Central knowledge management system for critical process parameters with sharing across sponsor and receiving sites Standard application platform adopted across plant network Islands of real-time process analytics Analytics semi-automated; 'where else can it happen?' Consition-based maintenance adopted Security risk and incident management centrally managed Environmental sustainability collected and reported to optimize energy management	Enterprise integration, orchestration of the end-to-end value chain through ecosystems fully integrated across process development, supply chain, maintenance, manufacturing and quality Digital twin models exist for certain asset classes and process to detect anomalies and predict events in near-real-time and recommend courses of action using AI Integration of product development and manufacturing including one-click digital tech transfer, based on process knowledge management system End-to-end supply chain visibility with limited external collaborations (suppliers/CMOs) In-line and at-line testing for some assays, fully integrated with the shop floor and lab system without duplicate entry unifying all quality release content to be reviewed by exception Integrated real-time process analytics to enable error-proofing using proactive analytics across plant and internal value; 'what can happen and when?' Smart maintenance, utilizing real-time data monitoring Real-time security risk incident management Environmental sustainabilty integrated with advanced analytics to optimize energy/water consumption in real time	Self-aware, continuously adaptive, 'autonomous' plant, exception conditions handled by remote experts Pervasive use of 'integrated value chain digital twin', powered by AI-driven models to autonompusly intervne and take action to maintain and enhance efficient , safe, reliable and high-qulaity operations across the value chain 'Plug-and-play everything' from instrument and recipes, to production or CMO Digital continuum allowing AI-driven tech transfer. Process and models are automatically genarated using a unified modeling language, powered by AI andbased process, equipmet and study data In-line, real-time, continuous, closed-loop, process verification and control with automated real-time quality release Zero system downtime (including upgrade)— continuous evolution Pervasive use of adaptive analytics and self/machine learning across value chain Intelligent maintenance; the plant can prevent and 'self-heal' the majority of equipment failures AI-based security risk and incident management, automating decision-making to deploy proactive security measures Net-zero sustainable plants with automatic optimization of supply chain choices, process optimization and intelligent facility design

Ref : BIOPHORUM IT - Digital Plant Maturity Model (DPMM) 3.0 - Addendum to the DPMM v1 white paper

Key: CMO = contract manufacturing organization, ERM = enterprise recipe management, ERP = enterprise resource planning, ISA = International Society of Automation, LES = laboratory execution system, MES = pharmaceutical manufacturing execution system, PLC = programmable logic controller and PLM = product development and manufacturing or production life cycle management or maintenance.

4. Educational Systems Need Retooling

A study in the United States revealed that only two percent of employers believe the current education system is effectively preparing young people for jobs in manufacturing.[29] Employers are adopting strategies, such as hiring statisticians and chemists, to fill roles formerly occupied by those graduates. This underscores the necessity of modernizing academic and other training programs.

Universities that provide instruction in pertinent fields might lack connections with industry experts who can collaborate to adapt training programs. Educators need a conduit to facilitate communication between academia and industry.

A 2017 European Council declaration likewise noted the need for "fundamental reforms of European education systems and their positioning towards future-oriented knowledge, skills, and competencies adapted to the digital age."[30] To secure their economic growth and security, European governments are investing strategically in biomanufacturing infrastructure through a well-skilled workforce. They expect industry and academia to ready workers for these new structures.

Beyond traditional scientific education in such disciplines as biology and engineering, the modern biopharmaceutical industry demands proficiency in data management, AI and automation. Transitioning to Industry 4.0 also calls for developing specific soft skills. Adaptability is paramount. In an ever-evolving technological landscape, employees must engage continuously in learning, unlearning, and training to keep their skills in sync with workplace demands.[31]

Key: autom. = automation, DevOps = software development and information-technology operations, eng. = engineering, mfg. = manufacturing, RM&C = resource monitoring and control, SOX 404 = Sarbanes-Oxley Act <404> compliance, QA = quality assurance.

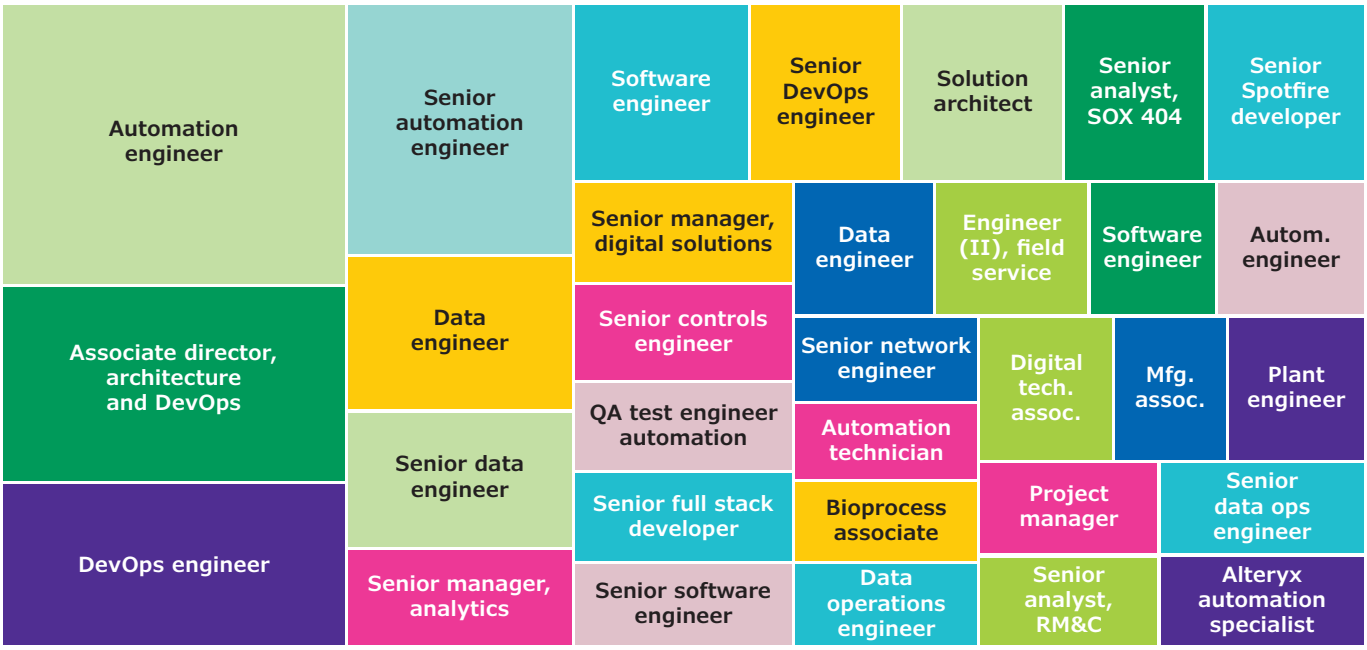

Figure 1. Shift in the Demand for Talent in Biotech Industry

Source: Biopharma 4.0 — the Talent Evolution (Jason Beckwith, Robbie Dool, Paul Rooney, Manish Thilagar, Stephen Goldrick, William Nixon, and Stavros Kourtzidis)

D. Strategies for Developing a Talent Pipeline

Automation, centralization and new job requirements could affect as much as 90 percent of today's biopharmaceutical manufacturing workforce.[32] To upskill the current workforce and successfully train future workers, employers and other public and private stakeholders need deliberate strategies. Such approaches include the following:

- **Hands-on Learning Environments:** Establish hands-on educational or proof-of-concept (PoC) spaces known as "learning/collaboration factories" where students can engage in real-world biomanufacturing processes with the latest solutions and technologies.
- **Diverse Hiring Practices:** Seek candidates with a mix of hard and soft skills to foster adaptability and creativity in problem-solving.
- **Promote 4.0-Specific Careers in Biopharmaceutical Manufacturing:** Implement targeted promotional campaigns that highlight the innovative and dynamic nature of careers in Biopharma 4.0.
- **Career Advancement Pathways:** Promote non-traditional routes for career development, including such as retraining workers from other industries including lateral entrants and career changes.
- **Strategic Workforce Planning:** Integrate workforce development into overall operations strategies to ensure alignment with Industry 4.0 requirements
- **Adapting Existing Training Programs:** Continuously update existing training programs and create new ones that reflect the latest technological advancements.[33]

Targeted government support and strategies for workforce development also will help.[34] Governmental bodies in Europe and other regions have acknowledged as much and are striving to expedite implementation. (See box on promoting innovation.)

1. National Initiatives to Promote Innovation in Biopharma Manufacturing

Over the last dozen years, nations have pursued digital advancements to enhance their manufacturing processes. Countries in all regions have implemented strategies and established structures for promoting Industry 4.0, such as training the workforce of the future. Consider this timeline.

- **In 2011**, the Government of Ireland opened a biomanufacturing training centre, the National Institute for Bioprocessing Research and Training (NIBRT), through its Industrial Development Agency, to conduct research and offer training not yet available elsewhere.[35]
- **In 2016**, the Italian Government introduced Industria 4.0, the national strategy to advance digitalization of the industry across sectors and to stimulate investments in manufacturing and relation innovation.[36]
- **Also in 2016**, the United States created the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) to fast-track standards, training and other activities to promote Industry 4.0 in biopharmaceutical manufacturing.[37]
- **In 2017**, Singapore launched the Smart Industry Readiness Index program to help companies adopt advanced technologies in manufacturing.[38]
- **In 2020**, the European Parliament endorsed Horizon Europe, the flagship EU program for technological innovation and competitiveness including scientific research and the application of digital technologies.[39]
- **In 2022**, France launched "France 2030" to boost the competitive position of French industries, including biotech.[40]

The evolution to Biopharma 4.0 requires a workforce with new skills, new ways of thinking, and creative problem-solving capabilities.

Government assistance has played a key role across all regions during and since the COVID pandemic in supporting R&D for novel technologies, assessing biomanufacturing infrastructure and supply chain resilience, and derisking investments to upgrade manufacturing capacity. Private companies have prioritized investments in digitalization and 4.0, accelerating the implementation of pre-existing strategies that might otherwise have taken years to put in place.

For example, with French national and regional governments, the European Investment Bank (EIB) co-financed a project called Bio'Occ (short for "biotherapy and bioproduction in Occitanie") in Toulouse.[41] The project attracted significant funding for the company Evotec and a biomanufacturing training center at the University of Toulouse.[42] The EIB viewed the project as part of the European competitiveness agenda linked to job creation, digitization, innovation, and sustainable growth.

In another project called CALIPSO (short for "online process sensors and innovative bioproduction solutions"), French public funding helped a consortium of Sanofi, Capgemini, GPC Bio, and others to seek "a new paradigm for bioproduction processes," to design new digital and connected tools for biomanufacturing that could speed production of certain biologics tenfold.[43]

A clear takeaway is that no single company, research institute, global health organization or other actor can do modern biomanufacturing and R&D entirely on its own. All stakeholders concur that the right workforce will be central to success. The proficiency of workers in biopharma manufacturing, R&D, and other functions is a key factor in a nation's absorptive capacity and a prerequisite for technology transfer and innovation. Enhanced performance in both domains can boost a country's capability to navigate uncertainty and adapt to change.[44]

Skills that appear most frequently in curricula of learning factories around the world.

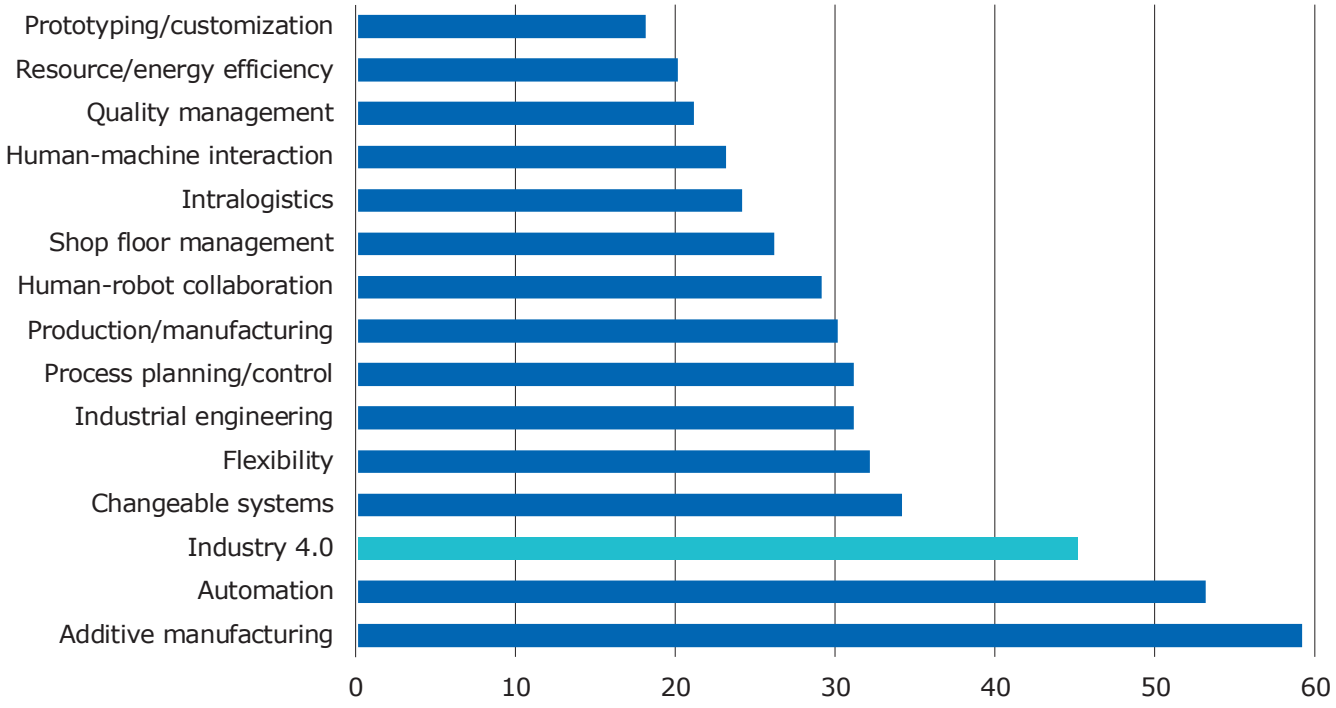

Figure 2: Top Skills Developed in Learning Factories

Source: *Maira Callupe, Elisa Negri and Luca Fumagalli, "An Inclusive Overview of Learning Factories Around the Globe,"* Proceedings of the Conference on Learning Factories (*May 10, 2021*), https://ssrn.com/abstract=3863491.

As organizations shift to strategic workforce planning over the long term, firms of all sizes will need a robust pipeline of skilled workers alongside strategies for employee retention.

2. Learning Factories

As the challenges and opportunities for manufacturing evolve, so do the requisite workforce skills. Having the right skilled workers is crucial for success in biomanufacturing 4.0. One approach involves hands-on training spaces known as "learning factories."[45] These approximate the experience of biomanufacturing facilities of the future, where staff can safety-test process improvements and modifications in production, and employees can upgrade their skills.

Such training facilities as those at NIBRT and at the Biomanufacturing Training and Education Centre on the North Carolina State University's Centennial Campus in Raleigh have proven suitable for mastering different aspects of the production process, such as lean management and energy efficiency.[46] Increasingly in recent years, more learning factories have added digitalization to their offerings to prepare workers properly for Industry 4.0 roles.[47]

Studies indicate that large companies tend to invest in their own workforce training, so that employees secure highly specialized skills. By contrast, smaller companies generally seek graduates who can hit the ground running within a lean operational model, where each employee performs a range of functions.[48]

As organizations shift to strategic workforce planning over the long term, firms of all sizes will need a robust pipeline of skilled workers alongside strategies for employee retention. To adopt Industry 4.0 principles and practices, they also will need to invest in re-skilling their existing workforce.

Technologies implemented on the shop floors of learning factories around the world in terms of instances. *Decision-making tools for managers include manufacturing executive systems, enterprise resource planning and product life cycle management.

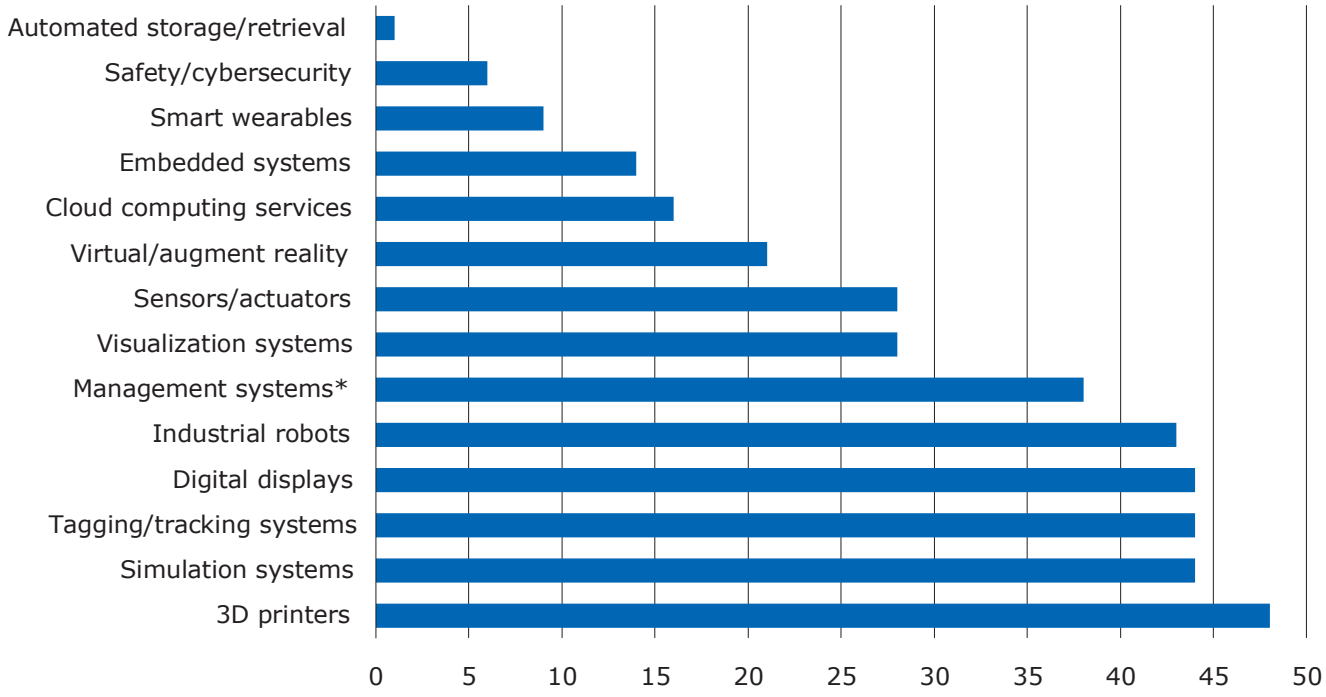

Figure 3: Top Industry 4.0 Technologies Used in Learning Factories

Source: *Maira Callupe, Elisa Negri and Luca Fumagalli, "An Inclusive Overview of Learning Factories Around the Globe,"* Proceedings of the Conference on Learning Factories (*May 10, 2021*), https://ssrn.com/abstract=3863491

3. Public–Private Training Initiatives

Developing new training programs in public–private partnerships is an effective approach to training biomanufacturing's future workforce.[49] By collaborating with industry, universities can keep job candidates up to date on equipment, processes and regulatory and compliance issues within the industry.[50] Such collaboration also can help to align the requisite skill sets for workers in different entry roles.

Education 4.0 has thus emerged as a business priority and an investment in the future and, therefore, high on the political agenda. European political leaders have long recognized the strategic importance of training on digitalization in their institutes of higher learning.

To support these training approaches, the European Commission has expanded funding for advanced biomanufacturing 4.0. Diverse biomanufacturing training initiatives sited in Europe are responding to this growing Industry 4.0 need.

In July 2021, for instance, the Commission approved €25 million for creating an EU Biotech Campus by 2025 in Belgium.[51] To cultivate the biomanufacturing workforce of the future, the campus will serve as a school and health hub including a business accelerator and a biomanufacturing training center with state-of-the-art infrastructure.[52] The hub will include training in automation, data collection and analysis, and management of connected supply chains, among other areas.

In addition to private sector and government-led initiatives, organizations such as the aforementioned NIBRT in Ireland and NIIMBL in the United States are helping to train the bioworkforce 4.0.

Opened on the campus of University College Dublin in 2011 and described as "a mini version of a pharmaceutical plant," NIBRT is a collaboration for workforce training that unites industry, government, and academia.[53]

NIIMBL, headquartered on the University of Delaware campus, publishes training resources, connects training programs with employers and works to promote careers in biomanufacturing among workers with relevant skills in other sectors.[54] It considers strong industry partnerships critical to developing new academic training programs for biomanufacturing 4.0.[55] So that its training programs respond effectively to market needs, NIIMBL also forms consortia to identify specific skills that biomanufacturing 4.0 workers will need. These efforts aim to raise awareness of these skills among human resources functions and harmonize approaches to credentialing.

In France, the Bio3 Institute provides training to research teams from companies, as well as professors and students from academia, in areas like quality control, and gives them access to equipment to gain experience in a simulated manufacturing environment.[56]

Merck Life Science contributes to onsite and remote training in advanced biomanufacturing through its global network of facilities known as M Lab™ Collaboration Centers.[57] The M Labs™ give scientists access to new ideas and techniques, cutting-edge equipment, analytical and modelling support, and other advice from Merck Life Science engineering and scientific experts. One is located in Molsheim, France.

Industry 4.0 training programs blend current and emerging information and communications technology (ICT), incorporate new learning methods, create innovative facilities to enable hands-on learning, and emphasize the development of core competencies required for success in an Industry 4.0 environment.[58]

4. Interdisciplinary Academic Training

Universities can move toward interdisciplinary academic training, so that graduates can work across multiple areas in biomanufacturing 4.0 and contribute to teams comprised of generalists and specialists. Students need hands-on training to acquire skills and knowledge so learning-by-doing approaches must complement classroom learning. Within these programs, virtual tools can complement rather than replace other types of training.

Developing new training programs in public–private partnerships is an effective approach to training biomanufacturing's future workforce.

The Lyon Consortium: Developing Innovative Bio-4.0 Training

Against this backdrop, we propose an innovative training program stewarded by a consortium of suppliers of bioprocessing equipment, expertise and services, biopharmaceutical manufacturers, professors and researchers from the Claude Bernard University of Lyon I, and experts in financing innovative economic development projects. This consortium was formed in 2023 in Lyon, France, with the goal to develop new approaches to training the biomanufacturing workforce of the future.

We developed an updated curriculum for training biomanufacturing 4.0 workers. It blends IT and scientific coursework to deliver the full range of skills necessary to succeed in the biopharma factories and R&D facilities of the future.

As global supplier of technology solutions, services and expertise to both industry and academia, consortium member Merck Life Science is well positioned to collaborate in the biopharma ecosystem to improve biomanufacturing 4.0 training at universities.

Together, academia and industry can work to cut a direct path to a career in biotech for those who master modern biomanufacturing techniques.

A. France as a Base: A Tradition of Bio-4.0 Excellence

We chose France as the base for this project for two reasons. First, the country has a long tradition of close university-industry collaboration, and institutions in France are already training the next generation of biopharmaceutical manufacturing workers there. For example, industry professionals can already explore novel modalities or test-drive advanced techniques at the French M Lab™ Collaboration Center one of Merck Life Science's interconnected labs. The global network of these Collaboration Centers exposes biomanufacturers to facilities staffed with scientific experts and equipped with cutting-edge technologies. Through collaborative exploration and hands-on learning, biopharma manufacturers of all sizes can achieve manufacturing excellence and innovation, without disrupting their own operations.

In 2022, France launched a Grand Challenges Biologics initiative to improve the efficiency of biopharmaceutical manufacturing through innovation in processes and the application of technologies like robotics. This initiative is central to the country's Healthcare Innovation Strategy 2030 (Innovation Sante 2030) which aims to lay a strong foundation for healthcare innovation and delivery by the end of the decade. Innovation Sante 2030 is part of the broader French digital strategy as well as its industrial plan, France 2030, which focuses on reinforcing excellence in biopharma and other industrial sectors to ensure French technology leadership on the global stage. The Grand Challenges Biologics initiative funds new platforms for coordination between industry and academia to advance biomanufacturing 4.0.[61]

Second, under its Health Innovation Plan, the French government has earmarked €1.5 billion for industrial investments in national projects that will support healthcare innovations.[59] (See box.) One such project is the aforementioned CALIPSO, a public-private platform aimed at developing novel micro-sensors, modelling production processes with digital twins and deploying AI to drive efficiencies tenfold at future biofacilities.[60]

The consortium is sited in the Auvergne-Rhône-Alpes (AURA) region and in Lyon in particular for four reasons: (1) they are home to the largest number of workers in the biopharma industry in France and they have track records in (2) running clinical R&D, (3) forming and managing public-private partnerships, and (4) training current and future industry employees.

1. Biopharma Employment

The Auvergne-Rhône-Alpes (AURA) region serves as a centre of excellence for biopharmaceutical manufacturing (also called a "biopole").[62] Home to 57 percent of biomanufacturing jobs in France, AURA is the second largest region in terms of employment, with the most manufacturing and R&D jobs of any region in France. More than 800 innovative biopharmaceutical sector small and medium-sized enterprises (SMEs) and start-ups have based themselves in the region, among such multinational leaders in the sector as Becton Dickinson, Biomerieux, Boehringer Ingelheim, Medtronic, Merck, Roche Diagnostics and Sanofi.[63]

2. Clinical Research and Development

In addition to its industrial and manufacturing credentials, the AURA region has established a reputation for relevant research and innovation in the biopharma sector. It boasts six university hospital centers, 14 hospitals, four clinical research centers, more than 22,000 clinical research professionals, 40 private-public research institutes, four higher education and research universities, and three—Pulsalys, Linksium and Clermont Auvergne Innovation—of France's 14 technology transfer acceleration companies (sociétés d'accélération du transfert de technologies
or SATTS).[64]

Through collaborative exploration and hands-on learning, biopharma manufacturers of all sizes can achieve manufacturing excellence and innovation, without disrupting their own operations.

3. Public-Private Partnerships

Like France overall, metropolitan Lyon has a robust track record of academia-industry partnerships through such programs and platforms as InnoBioVir, Mabdesign, Bioaster, Lyonbiopole and Biocluster, with the Trades and Qualifications Campus (Campus des Métiers et Qualification) coming soon.

InnoBioVir

Innobiovir, a technology platform at Lyon1 University, was created using financial support from the Aura region and the European Union. This technology platform supports biopharma R&D and innovation, uniting the Laboratory of Automation, Process Engineering and Pharmaceutical Engineering (LAGEPP) and the Laboratory of Virology and Human Pathologies (VirPath).[65]

With cutting-edge equipment from the Lyon Institute of Industrial Pharmacy (IPIL) and the University Institute of Technology (IUT), it offers continuing education and technical and scientific training to personnel in the biopharma industry.[66] Through InnoBioVir, these organizations can:

- Deliver continuing education on all aspects of the biomedical drug development and manufacturing life cycle,
- Offer bespoke services to partners from academia, industry and the start-up sectors,
- Develop custom education programs with industry partners,
- Leverage expertise in all aspects of biopharma R&D and manufacturing, and
- Support developing and optimizing molecular and cellular engineering processes, bioproduction, biomedicine purification, pharmaceutical formulation, quality control and evaluation of in-vitro and in-vivo efficacy.

Lyon academia-industry partnerships include InnBioVir, Mabdesign, Bioaster, Lyonbiopole, Biocluster, trades and qualifications campuses and training resources.

Mabdesign

Mabdesign, an industry association, is dedicated to the success of French biologics companies in France and abroad. With three hubs, one of which is located in Lyon, the association informs its member companies about market, intellectual property, technology, training, and other trends. It provides consulting services to help them secure financing, innovate, and better market their products and services. Mabdesign also trains biopharmaceutical employees (to date, 1600 biopharmaceutical employees from 150 companies), in addition to hosting Mabdesign Academy seminars where participants learn from industry experts about the latest treatments, manufacturing technologies and processes, and policy developments.

Bioaster

Bioaster is a microbiology technology institute founded in 2012 and headquartered in Lyon. Through public and private partnerships, it seeks to accelerate those projects that address global health issues. The institute specializes in molecular engineering, bioassays and optical engineering, preclinical model imagining, sata science and management, and clinical operations and the "omics" branches of science.[67] Bioaster helps its partners to manage scientific, technological and financial risks through holistic approaches and cost and return sharing.[68]

Lyonbiopole

As the AURA region's "health competitiveness cluster" of medtech, biotech and healthtech, Lyonbiopole represents a "health innovation network" of 275 members, of which 228 are SMEs.[69] Thus far, members have raised €218 million, launched 193 R&D projects, held 85 events and parlayed 500 job offers. Among its contributions to the Lyon innovation ecosystem, Lyonbiopole: hosts a network of the region's key biopharma players in science and technology, from industry, government and academi; advises academics, startups and incumbent firms in the region on their research, development, innovation and growth projects; catalyses public-private partnerships, and helps its members to grow through funding, staffing, global outreach and use of its R&D labs.[70]

Biocluster

A component of France's Health Innovation 2030 plan launched in June 2021, with a budget of €300 million, the innovation biocluster in Lyon seeks to: encourage top-notch research projects and multidisciplinary training; stimulate entrepreneurship and fast-track biopharma startups; and expedite public-private partnerships.[71]

Trades and Qualifications Campuses

Across the region, a constellation of 14 career campuses (called "Campus des Métiers et Qualification)—each dedicated to developing the skills and knowledge of a trade prominent in its locale—meets students where they are in their chosen profession. The Biotech Health campus that will be hosted in AURA brings together all the players involved in training and industry in the sector in order to promote employment and attract qualified professionals, support career development, and train for innovation, keeping up with industry trends and R&D.

Training Resources

The Lyon Consortium's approach to biomanufacturing workforce emphasizes inclusion, a core value of public universities in France. Access is a priority so as many talented students as possible can get the education they need. Given the growing supply-demand gap in biomanufacturing, consortium members aim to provide the largest number of motivated workers with access to relevant training in the coming years. In this respect, and with its important footprint and credentials in academic training and research, the public university in Lyon is a crucial partner.

The University of Lyon 1 anchors the regional biopharma ecosystem. It has three campuses and 11 sites in the region. With nearly 47,000 students, the university offers 17 bachelor degrees and 47 different master degrees, plus 10 health diplomas.[72] The school is a leading research institute, with 62 research laboratories affiliated with the campus and nearly €30 million in research contracts (i.e., scientific and technical collaboration agreements between laboratories and companies that share resources and knowledge).[73] It has 4,600+ staff members and nearly 3,000 teacher-researchers. As the leading French university in patent registrations, it spins off scores of startups each year. Because the public funds it, its students can afford degree programs regardless of their means.

B. The Project: Mapping and Filling Skills Gaps for Bio-4.0 Workers

Consortium members came together in spring of 2023 to determine the framework and scope of their collaboration, which they launched that same year. Leveraging the diversity of insights, perspectives and experiences of the participants, the consortium did the following:

First, it identified skills gaps faced by employers overall in the biopharmaceutical sector as opposed to the needs of individual organizations or companies.

Second, it identified the skills that graduates of public universities, notably Lyon I, acquired as they earned their degrees in biology, chemistry, and pharmacology, the fields in which universities normally train biopharmaceutical workers.

The Lyon Consortium's project creatively, efficiently, and effectively addresses critical workforce training needs in France, in a sector of vital public interest, through hands-on training delivery. The project further explores new funding strategies for universities, providing them with access to specialized experts on fundraising for procuring the necessary equipment for their 4.0 training programs.

Third, it mapped skills gaps and looked for innovative approaches to close them, such as developing new learning modules, deploying cutting-edge equipment on special terms for 4.0 training, offering cross-department courses to nurture the 4.0 skills of graduates interested in biopharma, and creating special projects to give students opportunities to gain hands-on experience with equipment. The Consortium aimed to provide ideas, information and other support to academia to update education programs.

Fourth, it aligned with broader national and European workforce development goals and collaborated with specialists to secure public financing for testing then potentially scaling the approach across France and beyond.

Key elements it needed to address for the project included foundational research, format of programs, sustainability, financing of equipment, and data collection, tracking and innovation.

1. Foundational Research on Needs

The consortium intends for the project to address real-world challenges related to training the biopharma workforce of the future, through practical effective action.

Initially, consortium members collected data through desk research, in-person consultations, and interviews with employers in the French biopharmaceutical sector. The team hosted three multistakeholder workshops in France. Also, between April and July 2023, it interviewed by telephone certain biopharma employers.

The desk research uncovered details about the requisite skills for Industry 4.0 in the biopharmaceutical sector, confirmed by multiple employer interviews. The team conducted multiple interviews because public universities must train graduates broadly for working in the sector, not just in one company.

The team used the same mixed research approach to identify existing relevant training programs for future biopharmaceutical manufacturing employees. Given their partnership with the University of Lyon 1, the researchers focused on the skills that students acquired during these training programs:

- Bachelor of technology course on biological engineering: Covering medical biology and biotechnology, this course provides senior technicians in all areas of biology with solid technical and scientific knowledge and communication skills.[74]
- Three master courses on industrial pharmacy: These degree programs train students for management positions in the health products industry with emphasis on technical-regulatory affairs, bioproduction and controls, and pharmaceutical development and production.[75]

The research team catalogued the skills that students ought to acquire in each of the above programs, not whether they successfully demonstrate mastery of those skills upon completion of the relevant degree program. Using the above approach, the team identified skills gaps in the French biomanufacturing sector; their findings serve as the foundation for developing targeted training programs. Training programs in the sciences, for instance, could benefit from the addition of cybersecurity, coding and big data management coursework.

2. Format of Educational Programs

Stakeholders can develop new training programs via different pathways, each presenting unique opportunities and challenges. For instance, any public university can create cross-departmental modules and new hybrid "diplomas" by combining different disciplines. However, creating a new undergraduate or master degree requires approval from the French Ministry of Education, and such approval can take many years. The quickest approach is to develop a module or university diploma, with a verifiable credential that the industry recognizes and values. Given urgent demand for biomanufacturing 4.0 workers, Lyon Consortium participants are exploring this option as a priority.

Universities can let students take classes from other parts of the university for credit towards their degree to acquire specific skills. Universities also can offer credit to those who work on special projects that require training in specific technical areas or on certain types of equipment. In this approach, students may value the opportunity to work with different connected biomanufacturing systems that they might encounter on the job, and so universities need a strategy for acquiring and maintaining such equipment. Such hands-on training is an effective means of preparing students for the facilities of the future. To design and help deliver these advanced training courses, universities can involve experts from industry or equipment manufacturers.

Approaches to training can vary. For instance, Merck Life Science regularly delivers training to employees via its Merck Academy—an educational platform for sharing Merck's expertise on such subjects as vaccinology, antimicrobial stewardship and the principles of biomarkers—and also as part of its contractual arrangements with customers. Companies like Merck can also offer to train professors who then train students. For this tactic to work, professors should be teaching, as well as doing research, to keep their knowledge current.

With the aim of providing training that meets the needs of industry 4.0 , the consortium developed an innovative conceptual syllabus combining scientific and IT training. Representatives of two public universities, one private training center and one biopharmaceutical innovator—all located in France—reviewed and endorsed the syllabus.

3. Financing

To attract top faculty and students, universities must consistently explore sustainable methods for acquiring, maintaining, and deploying state-of-the-art equipment. Financing poses a challenge for public institutions, as they contend with limited budgets for equipment purchases. One option is to share the cost of equipment across university departments, creating platforms that can be used by students from different disciplines and made available to employees wishing to upskill. Sometimes professors manage to identify the right equipment at the right price point, and then secure funds from French or EU government bodies. However, doing so is hard, not least because fundraising becomes a second job, and professors often lack the expertise to raise funds efficiently with results. One takeaway is clear and unanimous: professors should be

The Lyon Consortium addressed foundational research, format of programs, sustainability, financing of equipment, and data collection, tracking and innovation in order to map and fill skill gaps for Bio 4.0 workers.

teaching and conducting research rather than securing funds and buying equipment. For the latter, they need support from experienced partners, allowing them to dedicate most of their time to their students and their research projects. For such support, the Lyon Consortium includes finance specialists from the French firm ABF Decisions.

To address universities' financing challenges the Consortium brought in a specialized consulting group, ABF Decisions. Based in France, this group helps a range of clients to secure French and European funding for projects. ABF has substantial expertise in drafting applications, pitching projects, and building the right consortia around the project to improve the chances of a successful application. It also has relationships with banks, consultancies, capital fund developers, economic development agencies, and professional organizations and federations.[76]

The company works with private and public sector stakeholders, such as the Kedge Business School, the Audencia Business School, Université de Limoges and AFPI Formation, all of which educate and train current and future employees in France.[77] No laws or regulations prevent public sector non-profit entities from working with for-profit consultancies like ABF Decisions, subject to public procurement rules.

University representatives may express concerns about using public funds for private services, particularly if such service providers ultimately fail to secure funding. To address such concerns, ABF links its compensation directly to its results in what it calls a "success fee," calculated as a percentage of the funds raised. Some consultancies may also require an initial small retainer upfront.

The bottom line is straightforward: project teams have a clear legal and operational way forward, with minimal risk of spending public money without achieving the desired outcome, namely, to procure technologies for universities' biomanufacturing 4.0 training programs and labs.

The Lyon Consortium expects its project to create new training approaches for students, along with biopharmaceutical employees wishing to reskill and upskill. With this blended approach, the Universties could recuperate some of its costs by charging companies the market rate for sending their employees for training. This would require defining the credential earned and creating systems for its verification, in addition to promoting its value in the marketplace as credible and delivered by high-quality training institutes and centers.

4. Equipment

Having analyzed the training needs for biomanufacturing 4.0, the Lyon Consortium is working on procuring the relevant equipment (Table 2), in alignment with the proposed coursework for training students to join the workforce of the future of the biopharma industry. Drawing on its experience working with both academic institutions and biopharmaceutical manufacturers, experts from Merck Life Science identified the following types of solutions.

The project also brings forward the concept of creating novel virtual reality tools to train students on equipment. Companies are already using this approach to prepare employees for interacting appropriately with clean rooms and could apply it to other aspects of biomanufacturing.[78]

Table 2: Lyon Consortium: Merck Life Science Equipment Applied for Training

Technology	Merck solution	Description	Associated skills/roles
Digital – data collection and analytics	Bio4C ProcessPad™ Software	A data visualization, analytics, and process monitoring platform for bioprocess life cycle management, reporting, investigations, and continued process verification.	Digital, data management
Bioprocessing – equipment for continuous processing	Mobius® Breez Microbioreactor	A 2 mL fully automated single-use perfusion cell culture platform to accelerate applications such as cell line development, media screening and optimization, and early process development.	Research biologist
Process analytical technology – quality and process control	ProCellics™ Raman Analyzer with Bio4C PAT Raman Software	Raman spectroscopy fFor in-line and real-time measurements of CPPs and CQAs, from process development to manufacturing. It reduces the risk of contamination and batch failures and could support a nutrient control loop strategy, a first step towards automation.	Biologist; mathematics and multivariate analysis background; chemometric modelling
Process analytical technology – quality and process control	MAST® Autosampling Solution	A modality-agnostic, fully automated autosampling solution for the direct collection, delivery, and analysis of samples from multiple sources without manual intervention, acquire more frequent and consistent data points without intervening at any stage and analyze processes in hours instead of weeks.	Lab technician, biologist

5. Monitoring and Evaluation

To track impact, the consortium must collect and analyze data. Although the University of Lyon tracks its graduates' job placements — over 90 percent of graduates secure jobs within three years of graduation — the school does not track graduates in greater detail. Many universities typically lose touch with their graduates after their initial employment. The school does not monitor the challenges and opportunities of graduates as they enter the workforce, and how those relate to the education they received. Many institutes of higher education rarely capture such data for well-established degrees. At the same time, any institute launching new training programs would want to track the relevance of these programs to employment in biopharmaceutical Industry 4.0 contexts.

The Lyon Consortium, therefore, is developing appropriate metrics and methodology for collecting such information. It plans to continue engaging with employers, so that it can assess the relevance of the new training programs and use this information to modify the programs iteratively over time. This feedback, combined with data collection by organizations such as LEEM, the industry group serving the French pharmaceutical sector, will help to innovate new program features and, eventually, new programs.

The Way Forward

The Lyon Consortium's project creatively, efficiently and effectively addresses critical workforce training needs in France, in a sector of vital public interest, through hands-on training delivery. The project further explores new funding strategies for universities, providing them with access to specialized experts on fundraising for procuring equipment for their 4.0 training programs.

The creation of a multistakeholder, public-private consortium to ensure new training models align with needs across the sector in France and, more broadly, in Europe will contribute to safeguarding relevance of the new model. It is likely the approach can be replicated elsewhere. The Lyon Consortium expects to report publicly on the project's progress to inform similar efforts.

The Lyon Consortium exemplifies a successful public-private partnership aimed at addressing the skills gap in the biopharmaceutical sector by leveraging the diversity of insights, perspectives, and experiences of the participants.

Acronyms

Acronyms (Translations)			
AURA	Auvergne-Rhône-Alpes	M2M	machine to machine
BoT	Bachelor of Technology	mAb	monoclonal antibody
CALIPSO	Capteurs en Ligne de Procédés et Solutions Innovantes en Bioproduction (Online Process Sensors and Innovative Bioproduction Solutions)	MAST	modular automated sampling technology
CMO	contract manufacturing organization	MES	pharmaceutical manufacturing execution system
CO2	carbon dioxide	mL	milliliter
CPE Lyon	École Supérieure de Chimie Physique Électronique de Lyon (Lyon School of Engineering in Chemistry and Digital Sciences)	MTM	methods-time measurement (a process language stewarded by the MTM Association
CPP	critical process parameter	NIBRT	National Institute for Bioprocessing Research and Training
CQA	critical quality attribute	NIIMBL	National Institute for Innovation in Manufacturing Biopharmaceutical
DUT	diplôme universitaire de technologie (Technology Diploma)	OD	optical density
e.V.	eingetragener Verein (registered association)	OEM	original equipment manufacturer
EIB	European Investment Bank	OES	original equipment supplier
ERM	enterprise recipe management	OT	operational technology
ERP	enterprise resource planning	PAT	process analytical technology
FIR	Forschung–Innovation–Realisierung (Research–Innovation–Realization)	PLC	programmable logic controller
GDP	gross domestic product	PLM	product development and manufacturing, production life cycle management
I4.0	Industry 4.0	R&D	research and development
ICT	information and communications technology	ROI	return on investment
IPIL	Institut de Pharmacie Industrielle de Lyon (Lyon Institute of Industrial Pharmacy)	RWTH	Rheinisch-Westfälische Technische Hochschule (Rhenish-Westphalian Technical University)
ISA	International Society of Automation	SATTS	sociétés d'accélération du transfert de technologies (technology transfer acceleration companies)
IT	information technology	SME	small and medium-sized enterprise
IUT	Instituts Universitaires de Technologie (University Institutes of Technology)	VirPath	Laboratoire de Virologie et Pathologies humaines (Laboratory of Virology and Human Pathologies)
LAGEPP	Laboratoire d'Automatique, de Génie des Procédés et de Génie Pharmaceutique (Laboratory of Automation, Process Engineering and Pharmaceutical Engineering)	WBA	Weiterbildungsakademie (Continuing Training Academy)
LES	laboratory execution system		

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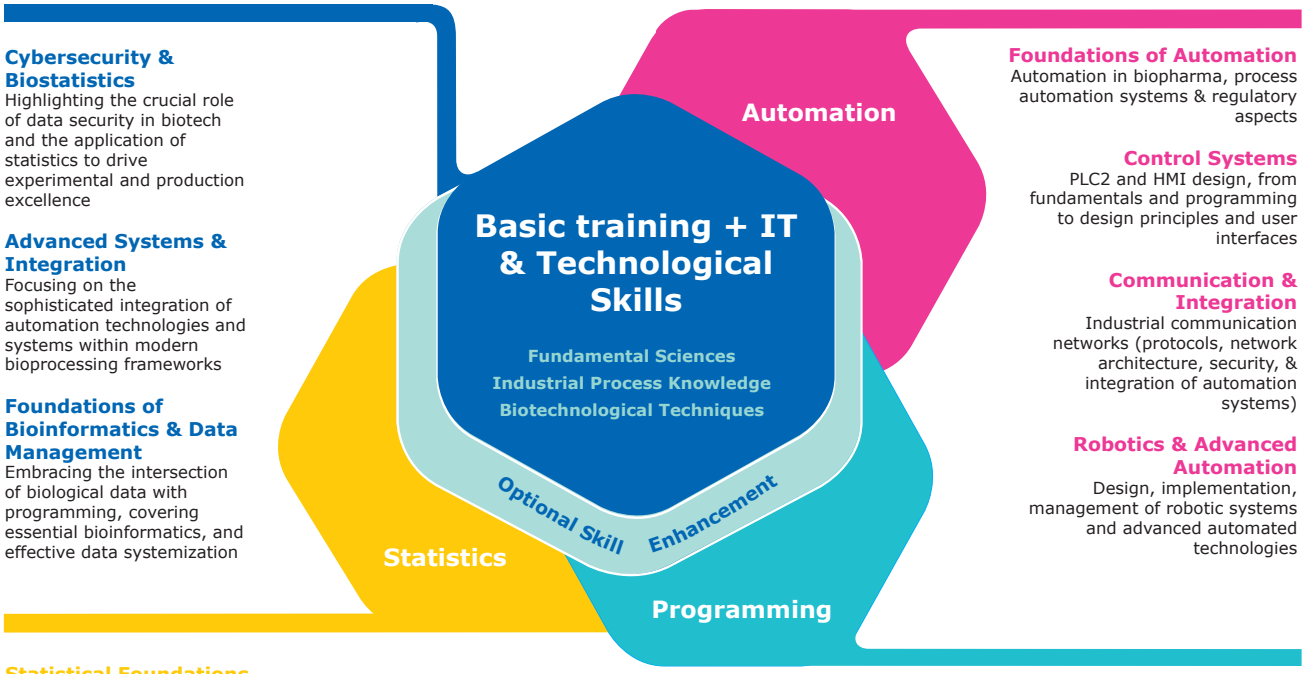
Foundational biological training combined with IT and technological skills, enabling the ability to expand expertise in additional areas such as statistics, programming, and automation



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Highlighting the crucial role of data security in biotech and the application of statistics to drive experimental and production excellence

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Focusing on the sophisticated integration of automation technologies and systems within modern bioprocessing frameworks

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Embracing the intersection of biological data with programming, covering essential bioinformatics, and effective data systemization

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Automation in biopharma, process automation systems & regulatory aspects

Control Systems
PLC2 and HMI design, from fundamentals and programming to design principles and user interfaces

Communication & Integration
Industrial communication networks (protocols, network architecture, security, & integration of automation systems)

Robotics & Advanced Automation
Design, implementation, management of robotic systems and advanced automated technologies

Statistical Foundations
Applied Statistics, Statistical Modelling, and Biostatistics

Advanced Statistical Techniques
Multivariate Analysis, Statistical Process Control, and Design and Analysis of Experiments

Data Management
Database Management Systems, Data Analysis, and Visualization

Core Programming
Object-Oriented Programming and Data Structure & Algorithms (Python)

Application Development
Web Development and any additional programming skills related to building applications

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