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Human–Machine Collaboration in Microbiological Laboratories: A Posthuman Perspective on Automation, Control, and Scientific Agency

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Abstract

The growing adoption of automation and intelligent technology in the microbiological laboratories is transforming the manner in which scientific knowledge is generated, and posing critical challenges of control, autonomy and agency. The current paper identifies the narrative review method to address the topic of human-machine collaboration via Posthumanism. It uses interdisciplinary literature to critically examine the role of automated systems in the way it goes beyond being a passive tool to the active shaping of experimental processes and decision-making. The results propose that scientific agency is not purely human, but it is shared in socio-technical assemblage where machines, algorithms, and biological systems work together to generate knowledge. Nevertheless, this redistribution creates tensions, such as less transparency, an accountability shift, and asymmetrical power relations that are embedded in technological devices. The paper proposes that automation does not only intensify human control but rather remakes it in complicated and mostly non-transparent ways. The post-humanist approach is necessary towards this understanding of the changing nature of scientific practice and in response to the epistemological and ethical aspects of an increasing automated laboratory space.

Keywords: *post-humanism, human-machine collaboration, automation, microbiological laboratories, control and autonomy*

Introduction

The growing adoption of automation and intelligent systems in microbiological laboratories is not only changing how the work is done in the laboratory but also the epistemic basis of scientific practice. Robotic pipetting systems, automated culturing systems, AI-based diagnostic systems, and other technologies are not isolated tools and peripherals anymore; they are moving to the center of the production, validation, and interpretation of microbiological knowledge (Lim, 2023). Although such developments are often posed in the context of efficiency, accuracy and standardisation, they imply deeper concerns with control, expertise and the agency location in scientific settings.

Conventional narratives of the laboratory practice place human subjects at the core of the decision-making process, and machines as passive tools. Nevertheless, this supposition will grow more problematic in those circumstances when automated systems affect the design of experiments, limit interpretative options, and formulate results (Mencacci, 2023). With the automation entrenched in lab practices, there is less differentiation between human will and machine action and as such, it can be argued that the role of agency in scientific labor is an area that needs reassessment.

Using Posthumanism and the perspectives of the Science and Technology Studies, the paper will challenge the anthropocentrism assumptions underlying the traditional perceptions of the

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laboratory science (Harada, 2023). A posthuman approach can reinvent labouratories as spaces of human-machine entanglement, in which the production of knowledge is generated by the interactions between a variety of human and non-human agents (Mara & Hawk, 2009). This paper is a critical analysis of human-machine collaboration in microbiological laboratories, and how automation changes the concept of control and scientific agency. It synthesises interdisciplinary literature to suggest that agency within the modern laboratory setting is shared among socio-technical assemblages with significant consequences to how scientific responsibility and scientific authority is construed.

Method

This study utilized a narrative review methodology to rigorously analyze human–machine collaboration in microbiological laboratories within a post-humanist perspective. A narrative method is suitable due to the intellectual and multidisciplinary characteristics of the topic, facilitating interpretive synthesis instead of systematic collection of factual data.

The literature search utilized ScienceDirect, ResearchGate, and Google Scholar, concentrating on works from around 2007 to 2023 to encompass both seminal post-humanist thought and contemporary developments in laboratory automation and artificial intelligence. Important search terms included combinations of "posthumanism," "scientific agency," "laboratory automation," "human–machine interaction," "microbiology," and "artificial intelligence in laboratories."

The inclusion criteria consisted of peer-reviewed journal articles, academic books, and conference papers that examined: (1) theoretical frameworks concerning posthumanism and agency, (2) automation and artificial intelligence in laboratory or clinical microbiology, and (3) human–machine collaboration within scientific or technological domains. Sources were chosen deliberately to guarantee conceptual significance, theoretical profundity, and interdisciplinary breadth, rather than comprehensive coverage.

The chosen literature underwent analysis through a thematic and interpretive synthesis methodology. Iterative identification of key themes revealed distributed agency, epistemic transformation via automation, reconfiguration of human roles, and tensions between control and autonomy. The review critically examines convergences and discrepancies among sources to construct a cohesive theoretical argument, recognizing the interpretive qualities and inherent subjectivity associated with narrative techniques.

Theoretical Framework: Posthumanism and Scientific Agency

The central concern of posthumanism is the anthropocentric belief that the human actors are the only source of knowledge, agency and control in the scientific practice. Instead of defining technology as a passive extension of the human intention, the posthumanist thinking redefines the idea of agency as a distributed aspect of the human and non-human actors and it is built through the entanglements of relations and not through individual agency. With the development of Posthumanism, it has also stressed the permeability of the boundary between humans, machine, and biological systems, thus disruption of conventional epistemologies in science (Ferrando, 2013; Miah, 2007).

At the center of this change is a re-conceptualisation of agency. Humanist approaches of tradition presuppose the agency of intentional human beings who manipulate passive instruments. This perspective, however, is dismissed by researchers like Kipnis (2015), who based on the actor-network theory, states that agency is not a characteristic feature but the consequence of interactions between heterogeneous entities. This relational conceptualization makes the concept of scientific control difficult, since it implies that results are produced in interaction with

instruments, algorithms, microbial systems and human operators. In the same vein, Bolton (2013) is undermining the premise of autonomous subjectivity by proving the way in which digital systems penetrate and redefine how human beings make decisions and thus permeate the boundaries between internal and external technological mediation.

This decentring of the human has great weight in the understanding of expertise in a scientific setting. According to Sage (2016), the presence of expertise is not confined to practitioners and also being spread throughout the tools, infrastructures, and social-technical arrangements. Building upon the point, Reader (2023) emphasizes that post-digital spaces contribute to the even greater undermining of the boundaries of human agency since the systems of algorithms are actively involved in the formation of knowledge production. This is more applicable in the laboratory where decision-making is becoming mediated by computational processes that are mediated beyond the immediate human perception.

Posthumanism does not, however, merely rejoice in such a redistribution of agency; it is within the process of bringing critical tensions as well. Lim (2023) warns against over-optimistic descriptions of relationality, claiming that not all the types of human-non-human interactions are symmetrical and fair. Likewise, Crano (2014) locates the posthuman agency to larger political-economic organizations, which implies that the technological systems may also support the control mechanisms instead of undermining them. These criticisms play a critical role in shunning an unsophisticated perception of posthumanism as being emancipatory in nature.

These views, combined, form a theoretical basis where scientific agency is seen to be contingent, distributed and materially mediated. This architecture facilitates a critical questioning of the process by which knowledge is generated and who or what might be said to be productive in scientific practice in microbiological laboratories where automated systems are actively involved in performing experimental processes.

Automation in Microbiological Laboratories

The microbiological laboratories have been at the forefront of automation and the scale and nature of the experiment work has changed. Modern systems combine robotics, machine vision, and artificial intelligence to be used in activities such as sample preparation, diagnostic interpretation, and diagnostic interpretation (Jensen, 2012). Though commonly presented as efficiency and accuracy achievements, these changes have a risk of washing out of the perspective the more radical epistemic changes that automation brings. According to Mencacci et al. (2023), the concept of laboratory automation is not a technical remodelling of generating, validating, and operationalising microbiological knowledge but a reorganisation of knowledge creation.

The introduction of machine learning into microbiological analysis makes this transformation even more difficult. As an example, Peiffer-Smadja et al. (2020) note that predictive algorithms are becoming popular to explain complex data, thus displacing at least some parts of diagnostic thinking in humans with computational machinery. This reallocation of analytical labour poses urgent challenges of regimes of transparency and interpretability, especially when the workings of the algorithm processes are performed as black box and no longer subject to direct human inspection. In this regard, the control is partial and mediate, but not absolute.

This is driven further by emerging technologies. The creation of artificial intelligence, including BacterAI, proves the ability of the artificial intelligence system not to require human knowledge but to self-map the microbial metabolism (Dama et al., 2023). This is a great shift to the conventional experimental paradigms, in which hypotheses and interpretations are explicitly anthropocentric. In this case, machines are no longer performing pre-coded tasks, but actively

creating new knowledge, that is, they are also part of knowledge creation, disrupting traditional divisions of tools and partners.

Simultaneously, the example of robotic systems that are used in accomplishing specific and accurate work in microbiological laboratories can explain the way automation transforms both physical and cognitive labour. According to Baumkircher et al. (2022), collaborative robots are capable of executing highly specialised processes with precision that is much greater than what humans are able to achieve but also means that new dependencies are created on technological infrastructures. Due to the growing standardisation of laboratory practices by automation, tacit knowledge and embodied expertise, which have long been at the heart of microbiological work, are at risk of death.

Notably, such developments cannot be construed in terms of technicality. The technological intervention, as Raffaeta (2022) suggests in the microbiome studies case, is creating an active reconfiguration of the definition of engaging with the microbial life, erasing the distinction between observation, manipulation and interpretation. Automation is therefore a mediating force but not merely a tool that determines the epistemic conditions of scientific inquiry. Such a change requires a redefinition of control and agency because with the growing autonomy of laboratory systems, the idea of humans as the main cause of scientific processes is becoming subject to doubt.

Human-Machine Collaboration: Reconfiguring Roles

The growing interconnection of automated technology into microbiological laboratories demands a restructured thinking of human-machine cooperation, specifically in the context of role and responsibility distribution, and decision-making power (Bolton, 2013). The modern technologies are not subordinate tools, but they are actually part of the laboratory processes, which in turn changes the role of human players in the scientific processes. Such a change is not only operational but also conceptual because it undermines established beliefs concerning the primacy of human expertise (Forlano, 2017).

Among the greatest changes, there is the reorganization of scientific labour. With automation replacing routine and precision-driven activities, human practitioners are rapidly being placed with the role of supervisors, interpreters and coordinators of machine-driven activities. Even in the virtual laboratory setting, as shown by Lisborg and Tafdrup (2023), learning and practice are no longer about direct human manipulation, but about the operation and interaction with technologically mediated systems. This shift is symptomatic of a larger trend towards following and not leading scientific processes, in which human actors are involved with the products produced by the process of complex socio-technical relationships.

This reconfiguration is however not without tension. With the development of so-called artificial sociality, as described by Komarova et al. (2021), one may assume that the relationship between humans and machines tends to be more of a collaborative connection, not hierarchy-based. Machines are also not just responding, adapting and controlling human behaviour in ways that are difficult to determine who is acting and who the passive recipient is. Empirical research of human-robot interaction, including Richter et al. (2023), also demonstrates that the cognitive states of human individuals, including hesitation and distraction, are also influenced by the interaction with automated systems, which signifies a reciprocal effect that disrupts the considerations of human dominant control. It is a dynamic that is becoming stronger at the frontier of scientific innovation. According to Harada (2023), the co-evolution of humans and AI-driven systems is pushing limits to what can be discovered scientifically, meaning that in the future, it is based on more integrated types of human-machine collaboration. In the

microbiological cases, it means that the knowledge production does not as much result on the isolated human reasoning as it is the product of distributed processes involving both the biological and technological actors.

According to the post-humanist approach, this reconfigurating of roles raises questions of the fact that collaboration is merely about humans being more efficient in the use of tools. Rather, it directs to a more multifaceted entanglement of agency, which is negotiated, shared and reinvented. Design and interaction should be perceived as processes that entail various types of agency, including the one, which is within the technological systems themselves as Posthumanism scholars like Forlano (2017) argue. Van Dijk (2020) also points out to the warning that even though posthuman interaction design does recognize those dynamics, it also needs to be aware of the implications of redistributing the power between human and non-human entities. Finally, the human-machine cooperation in the microbiological laboratories is something that cannot be simplified to an increase in the human ability. It is a reorganisation of scientific practice where the roles are fluid, the boundary is blurred and the agency is no longer strictly human. This requires the critical analysis of the negotiation of authority, responsibility and expertise in increasingly automated spaces.

Control vs Autonomy in Automated Systems

The correlation between control and autonomy in automated microbiological labs is commonly viewed in terms of artificial simplicity: automation is supposed to drive human control to higher levels in terms of efficiency, accuracy, and standardisation. Nevertheless, machine learning and intelligent systems are increasingly questioning this instrumental perspective since it makes the decision-making point of the human being much more complex (Jeong et al., 2021). Automation brings in new types of agency that exert control in disequilibrium, instead of merely extending human capacity.

On the one hand, researchers focus on the persistence of human control. As an example, Peiffer-Smadja et al. (2020) propose the idea that machine learning systems used in clinical microbiology serve as decision-support tools, but not as substitutes of human expertise. In this view, automation does not weaken the control, but restructures it, enabling human beings to work at a more abstract level. The assumption underlying this position is however that algorithmic processes can be interpreted and that they are subordinate to human judgement-a position which is becoming harder to maintain in practice. With increasingly complex systems, it tends to be impossible to explain or validate the full output of the systems by the human users, leading to the question whether oversight is really control or post hoc validation.

This tension is intensified when systems have some epistemic independence forms. The article BacterAI by Dama et al. (2023) illustrates that artificial intelligence can produce new information about the metabolism of microorganisms without previous assumptions and, in this way, change the locus of discovery of humans. Contrary to the so-called decision-support model, this implies a deeper shift of agency where machines are not aiding but actively guideline in areas of scientific investigation. The point made here is not merely the loss of control but the idea of the redefinition of what control is: when machines can be used to determine the paths of experiments, then human authority becomes contingent and not an essential condition.

The posthumanist views offer a helpful approach to explaining this shift, which is also internally disputed. On the one hand, basing his argument on Latour, Kipnis (2015) states that there is never a single agency and that human domination has been inflated even in the pre-digital environment. In this perspective, automation is not a new issue but merely brings to the surface the relational feature of agency that was never nonexistent. Conversely, Lim (2023) criticizes such relational

accounts because of the lack of consideration of asymmetries in power and cautions that all the actors in a network have equal influence. When applied to automated laboratories, this implies that, although agency can be decentralized, it is not decentralized evenly, in that algorithmic systems can have a disproportionate influence over the results even though they are not directly responsible.

Such criticism is supported by Crano (2014) who places the automation in more extensive neoliberal and technological systems of control. In this respect, the seeming independence of machines may hide how control can be re-centralised via infrastructures, data regimes, and institutional interests. That is, even what seems to be machine autonomy, it could be that the individual scientists have simply given away their control to more hidden forms of governance. This is opposed to more optimistic narratives, including Harada (2023), who discuss the human-AI co-evolution as an extension of scientific possibility but does not ask enough questions regarding the consequences of power and responsibility.

The consequence is the essential ambiguity the decentralisation of control and reconfiguration of control are simultaneous results of automation. It questions the notion that human beings can be the only masters of scientific action, but does not bring about an equivalent redistribution of power between people and machines. Rather, it is a fractured control, some of which is built into algorithms, some of which is held in the memory of human operators, and some of which is organized by institutional and technological systems. The key concern, however, is not whether control is being lost or being upheld but how it is being re-formed in a way that can be less visible, less accountable and less challengeable.

In this regard, the language of autonomy can be seen as striving to hide more than to show. When framing machines as autonomous agents, it becomes possible to obscure socio-technical conditions under which they can be active, at the same time, legitimising their capacity to engage in the process of decision making. A more critical method acknowledges that autonomy on automated systems is neither absolute nor neutral, but rather produced, placed and highly intertwined with transitional formation of power and agency in the laboratory setting.

Scientific Agency in a Posthuman Lab

The idea of scientific agency undergoes an essential metamorphosis in post-humanist thinking, as they cease being an individualised human ability and as a distributed effect through the interrelations between heterogeneous actors. Such reconceptualisation is not an empty hypothesis in microbiology laboratories that are now marked by automation and intelligent systems but is materially realised. Instead of seeing scientists as independent agents who guide the passive tools, agency needs to be perceived as produced collaboratively by human agents, computational systems, and biological materials.

One of the main arguments of the post-humanist scholarship is in relation to the nature and level of this redistribution. Based on the views of Latourian, Kipnis (2015) writes that agency was never solely human but rather a product of networks where human and non-human participants are involved. In this perspective, automated laboratory systems are not a new agency but are simply a revelation of relational dynamics on which scientific practice has long been based. Nonetheless, this posture is dangerous in suppressing valuable differences among actors. Lushetich (2022) builds on the argument with the notion of intra-action that one should assume the appearance of agency due to entanglement, but the relation ontology may hide inequalities of influence and responsibility.

Such asymmetries are paramount as far as the involvement of the sophisticated computational systems in the laboratory setting is concerned. Bolton (2013) emphasizes the fact that digital

systems can intrude and transform human cognition and refute the notion that agency is situated in the human subject. This can be observed in automated microbiological settings where machine outputs are used to interpret and make decisions and restructure the cognitive limits of science. Likewise, Ehrentraut (2019) believes that inter-relational subjectivities are created through human-machine mergers, where it is impossible to cleanly attribute agency, and through which the concept of authorship and accountability becomes more difficult.

Meanwhile, other researchers, including Sage (2016), highlight that expertise as a concept is distributed within systems of socio-technical systems implying that agency is distributed as well, and it is located within the infrastructures and tools. Such view corresponds to the empirical evidence of the technologically mediated settings such as virtual laboratories, where learning and action are configured through the ongoing interaction with the digital systems (Lisborg and Tafdrup, 2023). Lim (2022), however, based on the Deleuzian philosophy, warns of seeing these assemblages as harmonious or egalitarian, and focuses on their dynamic and frequently unequal formations, in which rivers of influence are contingent and changing.

This reconfiguration implication is further enhanced in the deeper scientific and ecological circles. According to Jeong et al. (2021), scientific agency, during the Anthropocene, is argued to be tangled with non-human systems, such as microbial and environmental processes, which go beyond technological mediation as the sole aspect of posthumanist insights. However, the widened concept of agency poses unanswered questions of responsibility. In case agency is decentralized, accountability is diffuse, which Crano (2014) locates in bigger politics-economic systems, where technological systems can reassign agency, yet at the same time, reenforce other kinds of control that are not transparent.

Collectively, these views indicate that scientific agency in a posthuman laboratory is not just generally shared or totally displaced. Rather, it is reproduced as an active and contentious process that arises to exist in the complicated interactions within the boundaries of human will, machine functioning, and biological functioning. This redistribution is difficult to identify one should not only be able to identify this redistribution but also be able to question its implication on authority, responsibility, and the generation of scientific knowledge.

Synthesis and Critical Implications

The above discussion has shown that automation of laboratories in the microbiology field does not merely increase the level of scientific practice, but it essentially restructures the aspect of control, autonomy, and agency. Throughout the literature, an apparent contradiction between views that define automation as a continuation of human ability, and the ones that define automation as a disruptive technology are present. Although there are explanations that accentuate continuity, implying that humans are still in control, by means of oversight, other accounts show that more and more control is seen to be mediated, incomplete, and even illusory. The synthesis of these views makes it clear that there is a critical change in the scientific practice that can no longer be conceptualised with an approach that involves human dominance over passive instruments. Rather it should be conceptualised as a socio-technical assemblage whereby agency is decentralised to interacting human and non-human components. This redistribution is however not a neutral one. The reorganization of agency, as postulated by Lim (2023) and Crano (2014) is often associated, as the author notes, with asymmetrical structures that favor some of its actors, specifically, technological systems and institutional structures, over others. As a result, collaboration language can sever dependences and power dynamics.

There are important epistemological and ethical implications of these dynamics. In case human-machines interact in producing knowledge, then the conventional concept of authorship,

expertise, and responsibility becomes wobbly. The attributability in complex systems is complex, which complicates the attribution of agency and therefore accountability, especially in high stakes situations like clinical microbiology. In addition, the growing cloudiness of algorithmic processes undermines the transparency of scientific legitimacy, which casts doubt on the issue of trust and verification.

Finally, posthumanist consideration is incorporated, which shows that automation is not a technical phenomenon but a restructuring of scientific power itself. It is important to acknowledge this change in order to come up with more critical and sensitive methods of governing and practicing automated laboratory science.

Limitations and Future Research

The research has some restrictions that are caused by its narrative and conceptually based style. The use of a chosen literature creates a level of interpretive subjectivity since the analysis is made more critical than comprehensive. Although this allows a more thorough synthesis of the theories, it can ignore other points of view, or new empirical observations. Also, the lack of primary empirical data inhibits the possibility to evaluate how posthuman configurations of agency are enacted and negotiated in the daily lab practice.

These gaps can be filled in future studies by adopting more empirical approaches, including ethnographic analysis or interviewing scientists who use automated systems in the field. A cross-study within various laboratory contexts may also enlighten the differences in the way the control and agency are disseminated. In addition, interdisciplinary efforts combining the knowledge of Science and Technology Studies, microbiology, and ethics would prove useful in coming up with more solid models of comprehension and regulation of human-machine partnership in scientific contexts.

Conclusion

The paper has suggested that automation in microbiological laboratories requires an essential reassessment of control, autonomy, and scientific agency. Beyond the instrumental explanations of technology as an objective extension of human ability, the analysis has revealed that automated systems actively engage in the technological process of experimental work, decisions and knowledge creation. The view of posthumanity is that agency cannot be identified as existing in human actors alone but should be conceptualized as being distributed in socio-technical assemblage involving machines, algorithms, and biological beings. More importantly, this decentralization of agency does not lead to a clear distribution of human agency but more difficult and sometimes opaque forms of power. Although automation might increase efficiency and analytical ability, it also creates interdependencies on systems that might be impossible to understand or control completely. Through this, the concept of control ends up being disaggregated and contingent as opposed to stable and centralised. To engage the future of laboratory science critically, it is important to identify these dynamics. Instead of raising the question on whether humans or machines are in control, the more urgent issue is how the agency is bargained, arranged, and held responsible in the increasingly more automated settings. The answer to this question can be crucial in making sure that scientific practice can be both epistemically firm and ethically accountable.

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