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RESEARCH ARTICLE

The Fourth Industrial Revolution (4IR) for pharmaceutical education in Brazil

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Abstract

Background: The Fourth Industrial Revolution (4IR) integrates digital, physical and biological technologies and is transforming many sectors, including pharmacy. In order to prepare future professionals for this new scenario, undergraduate pharmacy programs need to adapt to the new technological requirements. **Objectives:** This article analyses pharmaceutical education, focusing on the Brazilian National Curriculum Guidelines and their application and adaptation to the demands of the 4IR. **Methods:** To this end, a documentary survey analysed undergraduate pharmaceutical education in Brazil, considering the Pedagogical Program (PP) of ten programs with grades four or five in the National Higher Education Evaluation System (SINAES). **Results:** Despite some improvements, the 2a\curricula still reflect the previous industrial revolutions (2IR and 3IR) more than the innovations of the 4IR. **Conclusion:** The study concludes that it is necessary to update pharmaceutical education in Brazil and train professionals to integrate with emerging technologies.

Introduction

The first three industrial revolutions played a fundamental role in transforming the pharmaceutical sector, promoting the industrialisation of medicines manufacturing and the consequent change in education and the role of the pharmacist (Pötzsch, 1996). In Brazil, pharmaceutical education was late and poorly aligned with the demands of these Industrial Revolution. The lack of integration between technological advances and educational curricula may have contributed to gaps in pharmacists' training (Neves, 1994). In the Fourth Industrial Revolution (4IR) era, the opportunity to overcome these gaps has reappeared (Schwab, 2019; Baines, *et.al.,* 2020). For the purposes of standardisation and global recognition, this article uses the following abbreviations: First Industrial Revolution (1IR), Second Industrial Revolution (2IR), Third Industrial Revolution (3IR) and Fourth Industrial Revolution (4IR).

This 4IR era is marked by the integration of technologies such as internet of things (IoT), big data, and artificial intelligence (AI), bringing new challenges and possibilities to the pharmaceutical sector (Ambrosus, 2018; Baines *et al.,* 2020). Personalisation of services and customisation in manufacturing are emerging trends that require new skills and competencies from pharmacists (Gautam & Pan, 2016). However, when analysing scientific literature specifically focused on pharmaceutical education, we observe that development is still in its infancy and fragmented. Although there are some practical efforts that discuss the need for curricular reforms, active teaching methodologies, and continuing education (Christensen *et al.,* 2009; Alsharif, 2019; Cain, 2019; Baines *et al.,* 2020; FIP, 2020; Nouri, Hassali & Hashmi, 2020), the volume and depth of these discussions remain disproportionate to the speed of technological transformations that are reshaping the pharmaceutical sector.

The reviewed studies point out that the 4IR challenges pharmaceutical education to adopt new pedagogical models based on disruptive innovation (Christensen *et al.,* 2009; Maine, 2012; Abdel, *et.al.,* 2023), creativity and critical thinking (Cain, 2019), and digital and technological skills (Baines *et al.,* 2020). Propositional

models, such as TARGET (Nouri, Hassali & Hashmi, 2020), and international guidelines, such as those of the FIP (2020), advocate curricular restructuring and lifelong learning as ways to align pharmaceutical education with new digital demands. Nevertheless, evidence shows that these initiatives are concentrated in isolated experiences, without constituting a consolidated movement of educational transformation.

This mismatch between technological advances in the sector and the production of educational knowledge reveals a critical gap; while the pharmaceutical industry is rapidly advancing in the adoption of cutting-edge technologies, the training of future professionals still lacks pedagogical strategies that systematically incorporate these innovations. This scenario reinforces the need to expand the scientific and empirical basis of pharmaceutical education in the digital age, promoting integrated research that combines technological innovation, pedagogy, and professional practice as complementary axes for the future of pharmacy.

This article aims to analyse pharmaceutical education at undergraduate level, in the light of the emerging demands of the 4IR, in the context of disruptive technologies and innovations related to pharmaceutical products and services, and seeks to answer the following research question: What are the challenges for pharmaceutical education in the face of innovations promoted by the 4IR, considering the Brazilian context?

Methods

The documentary research was conducted using public and institutional sources, including official websites of higher education institutions, academic portals, university repositories that provide course Pedagogical Projects (PP), as well as official databases from the Ministry of Education and the Anísio Teixeira National Institute for Educational Studies and Research (INEP), as seen in Table I.

Table I: Industrial revolutions, technological foundations, and examples in pharmaceutical education

Industrial revolution	Technological foundation	Examples in pharmaceutical education
2nd Industrial Revolution	Industrial and chemical production	Traditional pharmaceutical technology, industrial drug manufacturing, physical-chemical control
3rd Industrial Revolution	Computing and automation	Health informatics, laboratory systems, analytical automation
4rd Industrial Revolution	Digital, biological, and physical integration	Artificial intelligence in healthcare, big data applied to the pharmaceutical sector, pharmacogenomics, personalised medicine, digital health.

In addition, an analysis was carried out of the Pedagogical Programme (PP) of a sample of ten pharmacy programmes, which obtained grades 4 or 5 in the 2019 stage of the SINAES (maximum grade = 5) and were available on their websites. Table II illustrates the sampling process. Supplementary A describes the rational process for the sample of pharmacy programmes.

A qualitative and exploratory approach was adopted, with an analysis of the Pedagogical Programmes (PP). Based on content analysis (Bardin, 2020), a protocol was developed by the authors (Supplementary B) and applied to the matrix of the PP of the selected programmes.

For the data extraction and categorisation phase, two PPs were independently reviewed, and data extraction and categorisation were conducted by authors PRB, NR and MRF. The results obtained in this small sample were compared and discussed to solve any disagreements and to reach a consensus. Then, PRB conducted the whole data extraction and pre-categorisation, followed by a group meeting to review and discuss the complete results.

Table II: Technologies and skills associated with the Fourth Industrial Revolution (4IR) used as an analytical framework

Category	Technologies/Skills
Digital health	Telemedicine, digital health, advanced electronic health records
Biotechnology	Pharmacogenomics, advanced molecular biology
Digital technologies	Artificial intelligence, machine learning, big data
Intelligent systems	Data-driven clinical decision support
Innovation	Entrepreneurship and innovation in health, development of digital solutions

For the purposes of this study, an operational definition of the Fourth Industrial Revolution (4IR) was adopted, based primarily on the research contributions of Klaus Schwab (2019); Oesterreich & Teuteberg (2016); Sakurai & Zuchi (2018); Almeida (2020); and contributions from Moreira (2018). These authors describe the 4IR as a phase characterised by the integration of digital, physical, and biological systems, driven by technologies such as artificial intelligence, the Internet of Things, advanced automation, big data, and biotechnology.

Based on this literature, it was considered that curriculum content aligned with the 4IR is that which explicitly involves: emerging digital technologies applied to health, advanced data analysis, intelligent decision support systems, advanced biotechnology, technological innovation, and entrepreneurship in health. On the other hand, content associated with previous industrial revolutions (2IR and 3IR) was classified according to its predominant focus on industrial processes, automation, or conventional digital technologies. Tables I and II establish criteria for distinguishing between 2IR, 3IR, and 4IR technologies and their applications in pharmaceutical education.

The documentary analysis was guided by three main categories, each one based on consolidated theoretical references in the areas of higher education, innovation, technology, and skills for the 4IR (Supplementary C). The following is a summary description of each category and the principles that underpin them:

a) Category I – Interdisciplinary collaboration for complex problem solving: assesses whether the curricula promote integration between different areas of knowledge, stimulating interdisciplinarity and a collaborative approach to real problems. Its rationale is based on studies on skills for the 21st century (Trilling & Fadel, 2009; OECD, 2018), active methodologies and experiential learning (Kolb, 1984; Biggs & Tang, 2011), as well as the importance of innovation and entrepreneurship in the context of 4IR (Schwab, 2019; Drucker, 1985).

b) Category II – Innovation, Entrepreneurship, and Curricular flexibility connected to the 4IR: examines the presence of pedagogical practices that encourage engagement with startups, interaction with the productive sector, and entrepreneurial training for students. The theoretical foundations used include open innovation and university-industry collaboration models (Etzkowitz & Leydesdorff, 2000; Chesbrough, 2003; OECD, 2019), the principles of curricular flexibility (Barnett, 2000), the importance of entrepreneurial education (Drucker, 1985; Ries, 2011), the role of mentoring (Gibb, 2002), and student engagement in innovation ecosystems (Kuratko, 2016; World Economic Forum, 2020).

c) Category III – ST&I Structures related to 4IR Technologies seeks to identify evidence of the integration of emerging technologies in curricula, the presence of innovation laboratories, incentives for research and development (R&D), and the application of innovative technologies in professional practices. The theoretical basis includes authors and documents that address the 4IR and digital transformation in education (Schwab, 2019; OECD, 2021), the role of innovative laboratory environments (Chesbrough, 2003; Belluzzo &Dudziak, 2009), national Science, Technology and Innovation (ST&I) policy (IDB, 2021), and the incorporation of technologies into professional practice in health and pharmaceutical training (Brasil, 2017).

The analysis of the results was classified into three levels: 1) Strong Evidence (EF): clear, systematic, and consistent presence of the item analysed; 2) Partial Evidence (EP): occasional mentions, without further elaboration or consistent articulation; 3) No Evidence (NE): total absence of references to the item. This classification is based on qualitative research protocols applied to the evaluation of educational policies described by Yin (2016) and Flick (2009), allowing the degree of integration of the themes in the analysed curricula to be identified.

The data extraction roadmap was defined by the four authors, and the first data extraction was conducted by one researcher and reviewed by the research team. Discrepancies (e.g., ambiguous responses) were resolved through iterative discussion with the team. All the researchers involved are professors with a vast experience in pharmacy education and health policies in Brazil. The team carefully considered how their background might affect the analysis and interpretations. The authors acknowledge the inherent subjectivity in the interpretation. To enhance rigour, three reflexive strategies were employed: peer debriefing, supervision of the coding process and consensus resolution, and systematic review of data consistency.

Results

In total, four institutional and historical documents were examined that supported the construction of the current DCNs for Pharmacy, among which the following stand out: a) The reports and systematisations produced within the scope of the First Brazilian Congress on Pharmaceutical Education (COBEF), held in

Salvador/BA, in June 2015 (CFF, 2015a); b) Contributions from the State Forums on Pharmaceutical Education, held between August and September 2015 in 24 states and the Federal District (CFF, 2015b); c) The consolidated document presented and approved at the II National Forum on Curriculum Guidelines, held in October 2015 (CFF & ABEF, 2015) d) Resolution National Education Council (CNE)/ Higher Education Chamber (CES) No. 06/2017 itself, a regulatory framework that institutionalised the National Curriculum Guidelines (DCN) for Pharmaceutical Education (Brasil, 2017).

A total of ten Pedagogical Programme (PP) for undergraduate Pharmacy were also analysed. The selection of documents considered public availability on the institutional portals of Higher Education Institutions (HEIs) and the presence of sufficient information to identify the axis "*Technology and Innovation in Health*," as defined in the 2017 National Curriculum Guidelines (DCN/2017). Of the set analysed, seven PPs were formally structured based on DCN/2017; However three PPs were still referred to Resolution CNE/CES No. 02 (Brasil, 2002), demonstrating an important delay in the curriculum update process. The period of publication of the documents varied between 2017 and 2024, which is a relevant interval for understanding the curricular evolution in the transition between guidelines, as well as institutional responses to technological transformations and new professional requirements.

Historical background: Brief account of the process of structuring the DCN for undergraduate pharmacy programmes in times of 4IR

Since the country's re-democratisation in 1985, and the promulgation of the 1988 constitution, discussions about the pharmaceutical profession in Brazil have called for a reorientation of training (Brasil, 1990). In 2002, pharmaceutical training began to be guided by Curriculum guidelines articulated with the country's health needs, prioritising context of the Brazil's Unified Health System (SUS) and health promotion (CNE, 2001). Resolution CNE/CES 02/2002 (Brasil,2002) established National Curriculum Guidelines for Pharmacy programmes, defining the training of pharmacists as generalist, humanist, critical and reflective. In Brazil, pharmacy graduates must be prepared to perform in healthcare, medicine development and manufacturing, clinical biology, and food quality control. These guidelines reinforce the need for training guided by ethical principles and social reality, seeking to transform pharmaceutical practice for the benefit of society.

In 2015, these guidelines underwent an evaluation and discussion process promoted by the Brazilian Association of Pharmaceutical Education (ABEF) and the Federal Pharmacy Council (CFF). The result was the publication of the new National Curriculum Guidelines (DCN/2017) for undergraduate Pharmacy programmes in Brazil (CFF & ABEF, 2015; Brasil, 2017).

Understanding the process of building the new Guidelines is important for the analysis in this study. At the 1st Brazilian Congress of Pharmaceutical Education (COBEF), the challenges and ways to improve pharmaceutical education were discussed, considering the changes in the sector, such as the enactment of Law 13.021/2014, which made pharmacies health facilities instead of commercial establishments only (Dalla Costa, 2015). During this period, discussions about the role of pharmacists providing health services, especially in community pharmacies, hospitals and the public funded institutions, took precedence over working in the pharmaceutical industry.

Subsequently, State level Forums on Pharmaceutical Education were held to evaluate the proposals, with a view to creating a theoretical framework that could consolidate the new curriculum guidelines. These debates, according to the established work matrix, should be based on the principles of training qualified, ethical professionals with the skills to meet the demands of society and the market, including pharmaceutical prescription, management, innovation and entrepreneurship, as well as contributing to sustainable national development.

The debates in the states addressed issues such as educational policies, graduate profiles, competencies, teaching-learning methodologies and practice scenarios. The results highlighted concerns about the lack of an articulated educational policy, adequate professors training, a gap in the graduate profile in relation to social and market needs, and the need for innovative and technological practices.

In the DCN/2017, graduate's competences were grouped into three main areas: Healthcare; Health Technology and Innovation; and Management. Practice scenarios must be designed both inside and outside universities to ensure training that is aligned with the needs of the market and society, training pharmacists who are able to contribute to improving public health and safety in the use of medicines (Brasil, 2017). Table III presents a summary of the proposals emerging from the debates held at the state forums on Pharmaceutical Education, promoted in 2015, with an emphasis on identifying curricular elements that dialogue with the principles and requirements of the Fourth Industrial Revolution (4IR). The systematisation

shows the total number of proposals discussed in each thematic axis of the DCN/2017, as well as the number and proportion of those directly related to the technological, social, and economic dynamics of the 4IR.

Table III: Summary and proportionality of proposals related to the Fourth Industrial Revolution (4IR) in the Consolidated State Forums on the DCN/2017 for undergraduate pharmacy programmes

Debated items	The total number of proposals that emerged from the debates	Number of propositions related to the subject of this study (4IR)	Highlights of the approach related to the topic under study
Premises	13	02	Adaptation to continuous learning; sustainable national development; production of technical and scientific knowledge for innovation
Education policies	09	01	Identify the role of the pharmacist in the new globalised world
Graduate profile	245	04	Training for social and market demands; managerial and entrepreneurial profile; innovation and development of pharmaceutical products; entrepreneurship and management
Competences	193	04	Management and health care; technology; entrepreneurial training. people and service management; human and social sciences; technological innovations; training for new technologies
Teaching methodologies	09	0	-
Practical scenarios	17	0	-

Source: CFF/ABEF, 2015.

The preliminary results of the discussions indicated the need to adapt content - or rethink the role of the pharmacist - due to concerns about continuous learning, training for innovation and new technologies, sustainable development and entrepreneurial training. In addition, themes such as innovation, social demands and entrepreneurship permeated the discussions, highlighting the dynamics of the 4IR, as highlighted in the final wording of the DCN/2017, which establishes the axis "*Technology and Innovation in Health*" (CFF/ABEF, 2015).

A final report consolidating the findings of these debates was approved and sent to the Ministry of Education as the proposal of the pharmacy sector and published by the CNE/CES Resolution No. 06, of October 19, 2017 (Brasil, 2017). As can be seen in article 5 of the aforementioned Resolution, the training of pharmacists should be structured around the following axes: I. Health Care; II. Technology and Innovation in Health and; III. Health Management (Brasil, 2017).

In the axis of Technology and Innovation in Health, the text defines health technology as the organised set of scientific, empirical, or intuitive knowledge applied to the research, development, production, quality assurance, and delivery of goods and services. Health innovation, in turn, refers to the search for solutions to technological challenges, involving the introduction or improvement of processes, products, strategies, or services that have a positive impact on individual and collective health (Brasil, 2017).

The 2017 Resolution outlines a set of competencies required for the effective implementation of the Technology and Innovation in Health axis within pharmaceutical education. These include the ability to engage in all stages related to health products — from research, development, and innovation to production, quality control, and assurance of the safety of medicines, pharmaceutical ingredients, biotechnological products, cosmetics, food, supplements, sanitising agents, and other relevant items (Brasil, 2017).

Furthermore, professionals are expected to manage technologies and services in the health sector, encompassing sustainable practices, infrastructure assessment, logistics management, and the integration of information technologies. They should also be capable of driving continuous improvement in processes, contributing to safer, more efficient, and technologically advanced healthcare environments (Brasil, 2017).

Analysis of undergraduate programmes in the face of emerging demands of the 4IR

The central purpose of the analysis was to examine the congruence of training with the demands and emerging

directions arising from the 4IR. In particular, an analysis was carried out of disruptive technologies and innovations relating to pharmaceutical products and services, seeking to identify gaps and opportunities for improvement in the pharmaceutical education curriculum.

With regard to the use of the DCN/2017, it was observed that of the ten Pedagogical Programmes examined, seven are based on the DCN/2017. The other three programmes are still based on DCN/2002. Table IV represents this data, adding information on the geographical regions, administrative category of the universities and the percentage of the workload applied to the Technology and Innovation in Health Learning Axis.

Table IV: Curriculum guidelines applied to the Pedagogical Programmes (PP) and percentage of the workload of the technology and innovation in health axis

	Courses analysed									
Categories of analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Pedagogical Programme in line with CNE/CES Resolution 06/2017	Applies	Applies	Applies	Applies	Applies	-	Applies	-	Applies	-
Workload of the Technology and Innovation Learning Hub (%)	40	40	40	40	40	-	40	-	40	-
Pedagogical Programme in line with CNE/CES Resolution 02/2002	-	-	-	-	-	Applies	-	Applies	-	Applies

When examining the subjects and content that were listed as belonging to the Health technology and Innovation Axis in the PP that adopted the DCN/2017, only one programme of the sample demonstrated evidences of integrated teaching strategies and content that have a robust interface with the dynamics, concepts and challenges of the 4IR, including, for example, artificial intelligence, nanotechnology, biotechnology, innovation, the creation of startups and entrepreneurship. On the other hand, the other programmes in the sample included teaching strategies and content with an emphasis on pharmaceutical technology, drug quality control, mass production techniques, industrial automation, pharmaceutical services, and other traditional educational practices that are notably more associated with the second and third industrial revolutions.

Based on the findings of undergraduate programmes, it is possible to state that the application of the DCN/2017 is unequal within the pharmacy programmes. Only one programme correlated the "*Health Technology and Innovation Axis*" to pedagogical strategies and content aligned with the principles of the 4IR, which suggests a disparity in the interpretation and implementation of the curriculum guidelines by the institutions analysed.

However, when analysing the conceptual approaches and general definitions contained in the PP, counter as components of the "*Health Technology and Innovation Axis*", there is substantial or partial evidence of the inclusion of these theoretical aspects in many of the PP. These theoretical references are found when interpreting the concept and definitions of the programme; the competences and skills; the profile and objectives of the course; and the professional profile of the graduate described in the PP. Table V shows the results of this analysis.

Table V: Evidence of general conceptual approaches related to technology, innovation, and entrepreneurship described in the course pedagogical projects.

	Analysed courses									
Evidences	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Program concepts and definitions	PE	NE	NE	SF	NE	NE	SF	NE	PE	PE
Competencies and skills	SF	PE	NE	SF	NE	NE	SF	PE	SF	SF
Programme profile	SF	NE	NE	SF	NE	NE	SF	NE	NE	NE
Program objectives	PE	NE	NE	SF	NE	NE	SF	NE	PE	PE
Professional profile	SF	PE	PE	SF	NE	NE	SF	PE	PE	PE

SE: Strong Evidence; PE: Partial Evidence; NE: There is No Evidence

Analysis of the theoretical approaches and pedagogical practices found in a sample of pharmacy degree courses shows that most of them demonstrate either partially or no evidence of alignment with the demands of the 4IR. Among the items investigated in the PP, the following stand out: fostering interdisciplinary collaboration to face complex challenges; encouraging the development of analytical skills and critical thinking to adapt to constantly changing environments; including practical learning methodologies, such as projects and internships, to apply concepts in real situations; developing interpersonal skills valued in today's job market, such as effective communication and teamwork; promoting a culture of continuous learning in the face of rapid technological change; addressing concepts of innovation, entrepreneurship and value creation to prepare students to identify opportunities and innovative solutions. The detailed results are shown in Table VI.

Table VI: Evidence on pedagogical approaches and practices related to technology, innovation, and entrepreneurship connected with 4IR, described in the PPCs

Evidences	Analysed courses									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
The curriculum promotes collaboration among different disciplines, encouraging interaction between knowledge areas to address complex problems.	PE	PE	PE	PE	NE	PE	PE	NE	PE	PE
The curriculum encourages the development of analytical skills, critical thinking, and problem-solving, allowing students to adapt to constantly changing scenarios.	PE	PE	PE	PE	NE	PE	PE	PE	PE	PE
The curriculum includes practical learning approaches, such as projects, internships, simulations, and laboratory experiences, that enable students to apply concepts in real situations.	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
The curriculum includes the development of competencies such as effective communication, teamwork, empathy, and resilience, which are increasingly valued in today's professional environment.	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
The curriculum promotes a culture of continuous learning, encouraging students to stay updated in the face of rapid technological changes.	PE	PE	PE	PE	PE	PE	PE	PE	NE	NE
The curriculum addresses concepts of innovation, entrepreneurship, and value creation, preparing students to identify opportunities and create innovative solutions.	PE	NE	NE	NE	NE	NE	NE	NE	PE	PE

SE: Strong Evidence; PE: Partial Evidence; NE: There is No Evidence

Also, with regard to the exploration of theoretical and conceptual approaches related to 4IR, Table VII highlights the results obtained from the following questions: a) Is there integration of students with startup events and programs? b) Is there a continuous connection with the pharmaceutical industry and the health innovation sector? c) Is there flexibility in the curriculum so that students can customise their studies according to their areas of interest and individual goals? d) Is there an opportunity to present Business Plans and/or Business Models? e) Is mentoring available from the teaching staff to guide students in business modelling? f) Is there encouragement to promote, organise and participate in innovation and entrepreneurship events?

Analysing the results of Tables VI and VII, it can be seen that, in the PP analysed, there is no record of "*Strong evidence*" related to pedagogical approaches and practices related to technology, innovation and entrepreneurship connected to the 4IR; there are 67 records of "*Partial evidence*", and there are 53 records of "*No evidence*".

Furthermore, when evaluating even more specific approaches described in chart III, the results are even remarkable in terms of the distance between the PP and the pedagogical topics related to the 4IR. In this table, the responses were: no records of "*Strong Evidence*"; 19 records of "*Partial Evidence*" and 41 records of "*No Evidence*".

Table VII: Evidence identified in PPCs on Science, Technology and Innovation (STI) frameworks and educational practices connected to the 4IR

Evidence	Analysed courses									
	1	2	3	4	5	6	7	8	9	10
Does the curriculum connect students with startup events and programs?	PE	NE	NE	NE	NE	NE	NE	NE	NE	NE
The curriculum maintains ties with the pharmaceutical and health innovation industry and active professionals in the field, allowing students to be aware of current demands and trends.	PE	PE	NE	NE	NE	NE	NE	PE	PE	PE
The curriculum offers flexibility for students to tailor their studies to their own areas of interest and goals.	PE	PE	NE	PE	PE	PE	PE	PE	PE	PE
The curriculum allows for the presentation of Business Plans and/or Business Models.	PE	NE	NE	NE	NE	NE	NE	NE	NE	NE
The curriculum, through its faculty or ad hoc mentors, provides mentoring for business modeling.	PE	NE	NE	NE	NE	NE	NE	NE	NE	NE
There is encouragement for the promotion, organisation, and participation in innovation and entrepreneurship events.	NE	NE	NE	PE	NE	NE	PE	NE	NE	NE

SE: Strong Evidence; PE: Partial Evidence; NE: There is No Evidence

Finally, table VIII presents the results of the analysis of the theoretical and practical pedagogical approaches described in the PP with a specific focus on the connection with the principles and demands of the 4IR. The data summarise the presence or absence of evidence related to the promotion of interdisciplinarity, critical thinking, innovation, entrepreneurship, and the use of practical teaching methodologies aimed at training professionals who are adaptable to constantly changing technological contexts. The analysis in Table VIII reveals the lack of integration of emerging technologies, such as artificial intelligence, machine learning, automation, IoT, and virtual/augmented reality, in the PP, as well as the absence of evidences of laboratory infrastructure focused on innovation in the courses evaluated. These data demonstrate misalignments between the current training content and the demands of the 4IR.

The Supplementary D presents excerpts representing the evidences (when applicable) for each category of the analysed PPs.

Table VIII: Category III: Integration of emerging technologies and ST&I structures in PP in relation to the 4IR

Categories	Analysed courses									
R&D&I structures related to 4IR technologies, described in the PP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Integration of emerging technologies: the curriculum incorporates artificial intelligence, machine learning, automation, the internet of things, and virtual/augmented reality.	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory infrastructure: the course offers innovation laboratories.	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Promotion of Research, Development, and Innovation (R&D&I)	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
Incorporation of innovative technologies in professional practices	PE	NE	NE	NE	NE	NE	PE	NE	NE	NE

SE: Strong Evidence; PE: Partial Evidence; NE: There is No Evidence

Discussion

The results described above rises important discussions. Apparently, considering the existence of a strategic axis called "*Technology and Innovation in Health*", one could understand that the DCN/2017 were explicitly concerned with the 4IR. However, looking at the document text in detail, this correlation is not clear, as the emphasis of this technological wave, marked by the Digital age, is centred on paradigms that go beyond traditional technologies, even if they are innovative. In this way, the training process for pharmacists also needs to prepare them for pharmaceutical intervention in relation to the rational promoted by the 4IR, whether in the field of design, planning, intervention, production and use of these technologies.

However, it is important to emphasise that the Technology and Innovation in Health axis provides support so that the pedagogical projects of the

programs can design curricula that support the new social and economic dynamics promoted by the 4IR and enter this new wave, which will certainly impact health technologies and, consequently, the financing of the SUS. In order to do this, it will be necessary to include the development and impact of this new wave in the premises, educational policies, graduate profile, competencies, teaching methodologies and practice scenarios of course pedagogical projects.

Taking the concept and dynamics of past industrial revolutions as a reference, it is possible to infer that both the definition of the Innovation and Health Technology Axis and the discussions arising from it are more oriented towards the 2IR and 3IR, which are based on the dynamics of synthesis, control and production of medicines and pharmaceutical services respectively.

In 2019, the event that brought together the 10th National Conference on Pharmaceutical Education and the 10th National Meeting of Program Coordinators had as its central theme "*Innovate and integrate*," seeking to propose dynamics and models of integration for the three axes of the current Guidelines. This event demonstrates a concern with innovation in the application of the DCN/2017. However, the discussion on innovation proposed in the central theme remained more limited to pedagogical strategies for professional training, with the potential to change the context of public health, as could be observed in the PP analysed.

Although there were general theoretical and conceptual approaches to technology, innovation and entrepreneurship and other dynamics related to the 4IR, there is a observable challenge in aligning the theoretical postulates with the reality of teaching in undergraduate programs. The PP analysed showed a need for greater integration, improvement, attention and application of these concepts to educational practice.

According to the specialised literature, innovation laboratories are structured environments for fostering the generation, development, and implementation of innovative solutions. They are designed to stimulate creativity, experimentation, and collaboration between different areas of knowledge and sectors of society, such as universities, companies, governments, and communities (Druker, 2002; Chesbrough, 2003; Hippel, 2005; Blank, 2020).

Such spaces, whether physical or virtual, are equipped with technologies and methodologies that facilitate processes such as design, prototyping, testing, and solution development. The absence of these structures in the PP analysed compromises the training of pharmacists capable of critically interacting with the technological advances of the Fourth Industrial Revolution (4IR), limiting the potential for innovation in the health sector.

Innovation laboratories have multiple purposes, from creating products, services, and processes to solving social and environmental problems. They often adopt interdisciplinary approaches and agile methodologies—such as design thinking, rapid prototyping, and iterative experimentation—to stimulate creativity and accelerate the generation of viable solutions. They can function as co-creation spaces, involving different social actors, or as startup incubation and acceleration centers, offering support to entrepreneurs and emerging companies (Liedtka *et.al.,* 2017)

With specific regard to the category "*promotion of research, development and innovation*", assessed in the aforementioned questionnaire, it was noted that all the PP examined showed Partial Evidence (PE) in this respect. This partial evidence, described in chart 04, was accounted for by the offer of scientific initiation programs in all the institutions in which the PP were examined. It is common knowledge that the central objective of scientific initiation is to introduce students to the world of academic research, promoting their immersion in this context and stimulating the development of scientific and investigative skills which, depending on how they are offered, may be in line with the purposes of the 4IR.

Limitations

As this is a documentary analysis, the findings are limited to the reports contained in the pedagogical projects and therefore portray an intentionality. In addition, the sample studied aims to explore the subject without the connotation of statistical representativeness. The results presented are limited to a sample of pharmacy courses with good results according to the national evaluation system and cannot be extrapolated to the universe of pharmacy programs in Brazil. The findings of this study could serve as a basis for future research with a larger sample and a longitudinal design to explore these aspects indepth.

Conclusion

The results of this investigation suggest that:

a) In Brazil, evidences suggest that the programs analysed reflect challenges observed in aligning pharmaceutical education with the principles of the 4IR, as set out in the "*Technology and Innovation in Health*" section of the DCN/2017, requiring coordinated technical, scientific, and political efforts;

b) The modernisation of educational infrastructure would benefit from accompanied by robust investments in the continuing education of faculty members, managers, and professionals, enabling them to understand and apply pedagogical and technological approaches compatible with the new digital age;

c) Collaboration between educational institutions, the pharmaceutical industry, and regulatory agencies may be an important strategy for building an integrated approach that promotes curriculum modernisation and strengthens the links between training, innovation, and professional practice;

d) The findings indicate the relevance of incorporating Curriculum updates should strategically incorporate content and practices related to artificial intelligence, big data, the Internet of Things, and other disruptive technologies with applications in pharmacy;

e) The findings highlight the relevance of fostering a culture of innovation and entrepreneurship among students and professionals in the pharmaceutical field as a key element for leadership in the face of technological transformations;

f) Strengthening research, development, and innovation structures, with a focus on 4IR, appears to be relevant to drive solutions applied to digital health and contemporary pharmaceutical practice;

g) Overcoming these challenges could contribute to enhancing Brazil's international competitiveness in the pharmaceutical sector, promoting scientific, technological, and industrial sovereignty in the field of health.

h) Through a comprehensive strategy that combines investments in education, technological innovation, and public policies for digital health, could strengthen Brazil's capacity to ensure a prominent role in the 4IR, strengthening the SUS.

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Conflict of interest

The authors declare that there are no conflicts of interest.

Ethics approval and informed consent

Not applicable. The study was based exclusively on public documents and did not involve human participants or personal data.

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