UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Engenharia Mecânica

GUSTAVO TIETZ CAZERI

Diretrizes para o desenvolvimento de conhecimentos dos gestores em Indústria 4.0

CAMPINAS
2022

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Tese apresentada à Faculdade de Engenharia Mecânica da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Doutor em Engenharia Mecânica, na Área de Materiais e Processos de Fabricação.

Orientador: Prof. Dr. Rosley Anholon
Coorientador: Prof. Dr. Luis Antonio de Santa-Eulalia

ESTE TRABALHO CORRESPONDE A VERSÃO FINAL DA TESE DEFENDIDA PELO ALUNO GUSTAVO TIETZ CAZERI, E ORIENTADA PELO PROF. DR. ROSLEY ANHOLON.

CAMPINAS
2022

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca da Área de Engenharia e Arquitetura
Rose Meire da Silva - CRB 8/5974

C319d
Cazeri, Gustavo Tietz, 1977-
Diretrizes para o desenvolvimento de conhecimentos dos gestores em Indústria 4.0 / Gustavo Tietz Cazeri. – Campinas, SP : [s.n.], 2022.

Orientador: Rosley Anholon.
Coorientador: Luis Antonio de Santa Eulalia.
Tese (doutorado) – Universidade Estadual de Campinas, Faculdade de Engenharia Mecânica.

1. Indústria 4.0. 2. Treinamento. 3. Formação de gestores. I. Anholon, Rosley, 1979-. II. Santa-Eulalia, Luis Antonio de. III. Universidade Estadual de Campinas. Faculdade de Engenharia Mecânica. IV. Título.

Informações Complementares

Título em outro idioma: Guidelines for managers to improve Industry 4.0 knowledge
Palavras-chave em inglês:
Industry 4.0
Training
Manager qualification
Área de concentração: Materiais e Processos de Fabricação
Titulação: Doutor em Engenharia Mecânica
Banca examinadora:
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Tiago Fonseca Albuquerque Cavalcanti Sigahi
Data de defesa: 15-12-2022
Programa de Pós-Graduação: Engenharia Mecânica

Identificação e informações acadêmicas do(a) aluno(a)
- ORCID do autor: https://orcid.org/0000-0002-7373-5003
- Currículo Lattes do autor: http://lattes.cnpq.br/4510475067681279

UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ENGENHARIA MECÂNICA

TESE DE DOUTORADO ACADÊMICO

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A Ata da defesa com as respectivas assinaturas dos membros encontra-se no SIGA/Sistema de Fluxo de Dissertação/Tese e na Secretaria do Programa de Pós-Graduação em Engenharia Mecânica.

Campinas, 15 de dezembro de 2022.

Agradecimentos

Primeiramente gostaria de agradecer a Deus. Tenho certeza de que sem fé nada seria possível. O desenvolvimento desta tese durante a pandemia de COVID-19 foi uma experiência única e diferente de todas as minhas expectativas anteriores. O "*lockdown*" no Estado de São Paulo teve início um dia após a aprovação da minha bolsa pelo CNPq e, de repente, eu e minha esposa tivemos que lutar para cuidar dos nossos filhos e do nosso trabalho. Isso gerou muitas noites sem dormir para cumprir os prazos necessários para o desenvolvimento desta pesquisa. Além disso, a necessidade de se evitar encontros presenciais exigiu alterações na escolha das metodologias de pesquisa a serem utilizadas.

Ao meu orientador, Professor Dr. Rosley Anholon, pela atenção, paciência e esforço incansável que contribuíram decisivamente para o aprimoramento contínuo desta pesquisa.

Ao meu coorientador, Professor Dr. Luis Antonio de Santa-Eulalia, pela atenção, orientação e dedicação no desenvolvimento deste trabalho.

À Professora Dra. Izabela Simon Rampasso, pela amizade e parceria.

A todos os que participaram dessa pesquisa, respondendo e analisando as questões apresentadas.

À minha esposa Fabiane, minha filha Lívia e meu filhinho Davi que me acompanham, apoiam e me dão força nos momentos de incerteza, principalmente durante o período de desenvolvimento desta tese.

Aos meus pais, João Luiz e Alzira, pelo total apoio, conselhos, carinho e confiança ao longo da minha vida e principalmente durante o período de desenvolvimento desta tese.

A todos que direta ou indiretamente contribuíram de alguma forma para este período de doutorado, meus sinceros agradecimentos.

O presente trabalho foi realizado com apoio do Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), processo n.º 140998/2020-9.

Resumo

Esta tese tem como principal objetivo propor e validar diretrizes para a disseminação de conceitos relacionados à Indústria 4.0 com foco em gestores de empresas de manufatura não familiarizados a esta temática. Para atingir este objetivo, quatro fases foram conduzidas. Na primeira fase, buscou-se refletir sobre os impactos da pandemia do coronavírus (COVID-19) na transição para a Indústria 4.0 no contexto do setor de manufatura brasileiro. Constatou-se que a pandemia do COVID-19 influenciou negativamente a transição do setor manufatureiro brasileiro para a Indústria 4.0 e, apesar de algumas empresas de classe mundial ainda continuarem a transição processo rumo à “Revolução Digital”, a maioria das empresas brasileiras de manufatura estão adiando importantes iniciativas relacionadas à Indústria 4.0 devido às incertezas. Na segunda fase, foram identificadas e classificadas as principais características exploradas pelas pesquisas atuais que englobam a formação para a Indústria 4.0. Através de uma revisão sistemática da literatura verificou-se que a maioria das pesquisas são voltadas para alunos de graduação e pós-graduação ou operários da indústria e, em geral, exploram assuntos técnicos, tecnológicos e humanos. Poucas pesquisas são direcionadas a gestores que lidam com a Indústria 4.0 e consideram conteúdos relacionados ao impacto da Indústria 4.0 em modelos de negócios, sustentabilidade, responsabilidade social corporativa e outros conceitos relacionados. Na terceira fase, foram identificados os principais desafios e validadas as melhores práticas a serem adotadas na realização de treinamentos ou programas de desenvolvimento sobre os conceitos da Indústria 4.0 para gestores que não os conhecem, mas aspiram a uma visão ampla do assunto. Para tal, foi aplicado respectivamente o método Delphi e o método *Fuzzy* Delphi junto à especialistas com experiência na transferência de conhecimento a outros profissionais e em Indústria 4.0. Em relação aos principais desafios, foram identificados onze temas agrupados em: desafios associados ao conhecimento necessário, desafios de quebra de paradigma, desafios associados as características do treinamento ou programas de desenvolvimento e desafios associados aos resultados esperados. No tocante às melhores práticas, dentre as doze apresentadas pela literatura, onze delas foram validadas para treinamento ou programas de desenvolvimento em Indústria 4.0. A quarta fase consistiu na validação do conteúdo adequado e o respectivo agrupamento do mesmo em módulos. A estrutura de conteúdo foi validada por meio do método Delphi com a participação de especialistas em desenvolvimento da Indústria 4.0 e considera um total de oito módulos ordenados da seguinte forma: Impacto dos Modelos de Gestão de Negócios; Personalização de Produtos e Produtos Inteligentes; Fábrica Inteligente e Integração; Modularidade e Orientação de Serviço; Descentralização e Interoperabilidade; Virtualização e Capacidade em Tempo Real; Responsabilidade Social Corporativa (RSC) e Impacto na Sustentabilidade; e Implementação da Indústria 4.0. Por fim, os resultados obtidos na terceira e quarta fase foram discutidos conjuntamente e analisados à luz de algumas das principais Teorias Gerais da Administração. Sob o ponto de vista prático, os resultados desta tese podem ser utilizados por consultores ou profissionais que atuam na área de desenvolvimento em Indústria 4.0, a fim de aprimorar seus cursos incluindo conteúdo ou públicos-alvo atualmente menos explorados. Do ponto de vista teórico, pesquisadores podem utilizar os resultados apresentados como guia para futuros trabalhos de pesquisa. Quanto a originalidade e relevância destaca-se a falta de pesquisas para desenvolvimento de gestores em Indústria 4.0 e a ausência de trabalho semelhante nas bases de dados científicas.

Palavras-Chave: Indústria 4.0; Desenvolvimento de Conhecimento; Treinamento; Gestores

Abstract

This thesis aims to propose and validate guidelines for training in Industry 4.0 basic concepts focusing on managers of manufacturing companies who are not familiar with these concepts. To achieve this goal, four phases were conducted. In the first phase, it was analyzed the impacts of the coronavirus pandemic (COVID-19) on the transition to Industry 4.0 in the context of the Brazilian manufacturing sector it was found that the COVID-19 pandemic negatively influenced the transition of the Brazilian manufacturing sector to Industry 4.0. Although some world-class companies are continuing the transition process towards the "Digital Revolution", the majority of Brazilian manufacturing companies are delaying important initiatives related to Industry 4.0 due to uncertainties. In the second phase, the main characteristics explored by current research that encompasses training for Industry 4.0 were identified and classified. Through a systematic review of the literature, it was found that the majority of current research takes into consideration undergraduate and graduate students or industry employees and, in general, explores technical, technological, and human issues. Few studies focus on managers who deal with Industry 4.0 and there is a gap in content related to the impact of Industry 4.0 on business models, sustainability, corporate social responsibility, and other related concepts. In the third phase, the main challenges in carrying out training on the concepts of Industry 4.0 for managers who are unfamiliar with them were identified and the corresponding best practices were validated. To this end, the Delphi method and the *Fuzzy* Delphi method were applied respectively to specialists with experience in transferring knowledge to other professionals and in Industry 4.0. Regarding the main challenges, eleven themes were identified and grouped into: challenges associated with the necessary knowledge, challenges of breaking paradigm, challenges associated with training characteristics, and challenges associated with expected results. On the subject of best practices, among the twelve practices presented in the literature, eleven of them were validated for training in Industry 4.0 through the application of the *Fuzzy* Delphi method. The fourth phase analyzed the appropriate content to be considered in the training and grouped it into modules. Through the application of the Delphi method with experts in Industry 4.0 training, the final content structure considers a total of eight modules ordered as follows: Business Management Models Impact; Product Personalisation and Smart Products; Smart Factory and Integration; Modularity and Service Orientation; Decentralisation and Interoperability; Virtualisation and Real-Time Capability; Corporate Social Responsibility (CSR) and Sustainability Impact; and Industry 4.0 Implementation. Finally, the results obtained in the third and fourth phases were jointly discussed and analyzed in the light of some of the main General Theories of Administration. From a practical point of view, these results can be helpful for consultants or professionals that work with Industry 4.0 training to improve their courses by including content or currently less explored target audiences. From a theoretical point of view, these results can be helpful for academics as they can serve as a guide for future research work. Regarding originality and relevance, there is a lack of research on training managers in Industry 4.0, and no similar study was found in scientific databases.

Keywords: Industry 4.0; Knowledge Development; Training; Management

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1. INTRODUÇÃO

1.1 Contexto da Pesquisa

Nas últimas décadas, o avanço nos sistemas produtivos tem sido estimulado principalmente pela necessidade das organizações em se manterem competitivas. Frente a um mercado globalizado e marcado por constantes mudanças, as respostas rápidas dos sistemas produtivos se caracterizam como elementos essenciais (HOU *et al.*, 2020). Tais avanços são cada vez mais marcados pela inserção da tecnologia no ambiente fabril, gerando mudanças de paradigmas ao longo de toda a cadeia produtiva e nos próprios modelos de negócio (ARNOLD; KIEL; VOIGT, 2016; IBARRA; GANZARAIN; IGARTUA, 2018; MÜLLER; BULIGA; VOIGT, 2018).

Os últimos dez anos, em especial, tem sido caracterizado pela vertente da digitalização e inovação dos processos e modelos de negócio, também conhecida como a quarta revolução industrial ou, simplesmente, Indústria 4.0 (KUSIAK, 2018; ROJKO, 2017; THOBEN; WIESNER; WUEST, 2017; WILKESMANN; WILKESMANN, 2018). Este último termo foi promulgado pela primeira vez na Feira de Hannover em 2011 pelo governo alemão (GHOBAKHLOO, 2018; OZTEMEL; GURSEV, 2020) e, a partir de então, tem sido cada vez mais citado no meio acadêmico e empresarial (BENITEZ *et al.*, 2019; LASI *et al.*, 2014; OZTEMEL; GURSEV, 2020; PEREIRA; SANTOS; CLETO, 2018). Em função dos seus recentes benefícios, bem como vantagens futuras ainda não totalmente compreendidas, o movimento da Indústria 4.0 vem recebendo apoio governamental não somente na Alemanha, mas em diversos países como Estados Unidos, China, Japão, Korea, entre outros (KANG *et al.*, 2016; XU; XU; LI, 2018; ZHONG *et al.*, 2017)

Diante desse novo cenário, que visa combinar todos os agentes de produção (máquinas, robôs e operadores) por meio de redes de conexões e gerenciamento da informação na forma de sistemas ciber-físicos (ARDITO *et al.*, 2019; GHOBAKHLOO, 2018, 2020; HERMANN; PENTEK; OTTO, 2016; OZTEMEL; GURSEV, 2020), considerava-se inicialmente que a implementação da Indústria 4.0 resultaria em uma fábrica com o mínimo de intervenção humana. Entretanto, essa concepção foi abandonada logo após o surgimento do termo e uma visão holística vem sendo adotada baseada em três fatores principais: tecnologia, organização e fatores humanos. Por fatores humanos compreende-se a manutenção da necessidade de intervenção humana na Indústria 4.0, ou seja, a Indústria 4.0 requer constante interação de colaboradores, porém de maneira atualizada, com relação a tecnologia e a organização em que atuam. (DREGGER *et al.*, 2016; ITTERMANN; NIEHAUS; HIRSCH-, 2016; REUTER *et al.*, 2017).

Sony; Naik (2020) concluíram que, dentre dez fatores críticos de sucesso para implementação da Indústria 4.0, ao menos três deles estão ligados ao aspecto humano (alinhar as iniciativas da Indústria 4.0 com estratégia organizacional; apoio incondicional da alta direção para as iniciativas da Indústria 4.0 e importância dos colaboradores para o sucesso da Indústria 4.0). Conforme Jain; Ajmera; Davim (2022), a resistência dos colaboradores em adotar novas tecnologias apresenta-se como a maior ameaça a implementação da Indústria 4.0 e a necessidade de desenvolvimento de pessoas com habilidades especializadas como a maior fraqueza. Portanto, o desenvolvimento de pessoas de forma contínua merece especial atenção e importância para a Indústria 4.0. Kaya *et al.* (2020) e Schallock *et al.* (2018) reforçam a relevância do fator humano e destacam o desenvolvimento profissional como a estratégia mais importante a ser adotada por organizações durante o processo de transição para a Indústria 4.0.

Bakhtari *et al.* (2021) apresentam a falta de visão e liderança da alta administração, falta de programas de treinamento, desenvolvimento de habilidades e educação e falta de força de trabalho qualificada como os principais desafios na implementação da Indústria 4.0 em indústrias de manufatura. Especificamente para pequenas e médias empresas, Devi; Paranitharan; Agniveesh (2020) e Moeuf *et al.* (2020) apresentam o desenvolvimento de pessoas como um dos principais fatores críticos para o sucesso na implementação e manutenção da Indústria 4.0.

Torna-se evidente assim que programas de desenvolvimento e treinamentos referentes a disseminação e implementação de conceitos relacionados a Indústria 4.0 passaram a ser imperativos nesse cenário e métodos de desenvolvimento de pessoas ligados a Indústria 4.0 ganham importância, caracterizando-se como lacunas de pesquisa a serem exploradas (SPÖTTL; WINDELBAND, 2021; TOMMASI; PERINI; SARTORI, 2021). É preciso analisar as formas mais adequadas e eficientes para transmitir conceitos aos participantes (BAENA *et al.*, 2017; HELMING *et al.*, 2019; KOLEVA; ANDREEV, 2018; MOLINO; CORTESE; GHISLIERI, 2020; PERINI *et al.*, 2017; SILVA; OLAVE, 2020).

A norma ISO 10015:2020 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2020) fornece diretrizes para a gestão do desenvolvimento de pessoas de maneira a contribuir para que os investimentos das organizações nesse quesito tornem-se mais eficientes e eficazes. Essa norma estabelece o conceito de desenvolvimento de pessoas com base na aquisição de novas competências, as quais devem ocorrer através da criação de treinamentos e oportunidades de aprendizado alicerçadas em situações relacionadas as práticas aplicadas na organização.

Ainda conforme a norma ISO 10015:2020, a competência do capital humano é definida como capacidade de aplicar conhecimentos e habilidades para alcançar os resultados pretendidos. Adicionalmente, a norma ISO 10015:2020 enfatiza a importância do desenvolvimento de pessoas no processo de melhoria contínua em uma organização.

Como mencionado na norma ISO 10015:2020, os termos "desenvolvimento de pessoas", "treinamento" e "aprendizagem" são correlatos e a literatura acadêmica apresenta similaridades e diferenças entre os mesmos. Conforme Masadeh (2012), o termo "desenvolvimento" passou a ser utilizado com maior frequência a partir da década de 1950 e, muitas vezes, como sinônimo do termo "treinamento". Entretanto, a literatura acadêmica atual apresenta distinções entre esses termos.

A maioria das definições apresentadas pela literatura acadêmica atual enfatizam que o treinamento possui maior foco em um trabalho específico e em competências básicas. Trata-se de um esforço planejado e sistemático para modificar ou desenvolver conhecimentos, habilidades e atitudes a fim de contribuir com o desenvolvimento da organização através de um desempenho eficaz em uma determinada atividade ou uma série de atividades. Destina-se a um impacto imediato no trabalho ou função que se desempenha (FITZGERALD, 1992; GARAVAN, 1997; MASADEH, 2012). McDowall; Saunders (2010) reforçam esse contexto, apresentando que gerentes responsáveis por treinamentos relacionam o sucesso do mesmo com melhorias nas habilidades dos participantes e priorizam o treinamento formal devido a um retorno do investimento demonstrável e tangível.

Por outro lado, o desenvolvimento de pessoas possui maior foco em uma mudança de atitude a longo prazo e sem o objetivo principal de contribuir com o desempenho de uma ou uma série de atividades específicas na organização. Este refere-se a aquisição de conhecimentos e habilidades que podem ser usados no presente ou no futuro e que visam a preparação de indivíduos para enriquecer a organização no futuro (FITZGERALD, 1992). Dessa forma, o "desenvolvimento" é direcionado a uma atividade de aprendizado a médio e longo prazo e destinada a uma função ou trabalho futuro.

Em todos esses conceitos nota-se a importância da aprendizagem, a qual refere-se a um processo holístico, que engloba o treinamento e o desenvolvimento, no qual o indivíduo experimenta uma mudança, seja de maneira comportamental, afetiva, estrutural ou física (GARAVAN, 1997; MASADEH, 2012).

1.2 Problema de Pesquisa, Justificativa e Relevância

Diante do contexto acima apresentado, verifica-se a relevância do desenvolvimento do capital humano para a Indústria 4.0 (CEREZO-NARVÁEZ; OTERO-MATEO; PASTOR-FERNÁNDEZ, 2017; SCHALLOCK *et al.*, 2018; SONY; NAIK, 2020) e torna-se importante destacar que não foi encontrada na literatura acadêmica qualquer revisão sistemática que possa potencializar o desenvolvimento de conhecimentos para gestores não familiarizados em Indústria 4.0. Dos estudos na área, destacam-se Benitez *et al.* (2019), Brizolla; Patias; Dorion (2019) e Sony; Naik (2020), os quais apresentam que o papel de profissionais que ocupam nível hierárquico gerencial e cargos de gestão em uma empresa é um fator crítico de sucesso na disseminação e implementação de conceitos relacionados a Indústria 4.0. Sony; Naik (2020) apresentam o gerenciamento da mudança organizacional como um aspecto imperativo para o sucesso da Indústria 4.0. Este deve ser liderado pelo diretor ou presidente da organização e conduzido pelos gestores, os quais devem fornecer a visão correta, criar a cultura adequada e realizar as alianças necessárias dentro da organização para a implementação da Indústria 4.0.

A função dos gestores na transição para a Indústria 4.0 é particularmente relevante no Brasil, no qual a disseminação e implementação da Indústria 4.0 mostra-se em seu estágio inicial. De um lado, tem-se a dificuldade das empresas presentes em território brasileiro realizarem investimentos em tecnologias a fim de tornar seus sistemas de produção inteligentes e digitais (CNI, 2018; RUGGERO *et al.*, 2019); de outro lado, existem muitas empresas sem o conhecimento básico sobre Indústria 4.0 (FIESP, 2018; FIRMINO *et al.*, 2020). Conforme pesquisas realizadas pela Confederação Nacional da Indústria (CNI) e pela Federação das Indústrias do Estado de São Paulo (FIESP), grande parte da indústria brasileira ainda se encontra em processo de familiarização dos conceitos de digitalização e de seus impactos nos modelos de negócio setoriais e com conhecimento raso sobre Indústria 4.0 (CNI, 2016; FIESP, 2018). Segundo FIESP (2018), dentre um total de 227 empresas pesquisadas no Brasil (55% pequenas indústrias, 30% médias indústrias e 15% grandes indústrias), 73 delas (quase um terço) desconhecem o termo “Quarta Revolução Industrial”, “Indústria 4.0” ou “Manufatura Avançada”. Este cenário é reforçado por Firmino *et al.* (2020), o qual verificou que em 47 empresas de manufatura instaladas na Região Metropolitana de Sorocaba (conjunto de 27 cidades do Estado de São Paulo), a maioria desconhece a expressão “sistema físico cibernético” ou “*Cyber Physical System*” (CPS).

Somado a este cenário, a ocorrência da pandemia do coronavírus (COVID-19) desencadeada na China a partir de março de 2020 (WORLD HEALTH ORGANIZATION, 2020), sendo o Brasil o segundo país do mundo com maior número de mortes por COVID-19 (WORLD HEALTH ORGANIZATION, 2022), trouxe impacto no setor econômico com perdas de empregos e redução na necessidade de commodities e produtos manufaturados *(NICOLA et al.*, 2020). Consequentemente, tem-se um impacto na disponibilidade das organizações em investir em tecnologias para digitalizar seus sistemas de produção e essa nova realidade impacta a implementação da Indústria 4.0 em economias emergentes, como o Brasil (BIANCO *et al.*, 2022; PAUL *et al.*, 2021; PEDOTA; GRILLI; PISCITELLO, 2023).

Assim, conforme as características apresentadas anteriormente: 1) necessidade de implementação da Indústria 4.0 para que as organizações mantenham-se competitivas; 2) desenvolvimento de conhecimento dos colaboradores, e em especial dos gestores, é fator crítico de sucesso e fator estratégico no processo de transição para a Indústria 4.0; 3) o cenário brasileiro encontra-se em fase inicial de transição para a Indústria 4.0 com carência de conhecimento sobre o tema, sendo impactado pela pandemia do coronavírus (COVID-19); este trabalho busca responder o seguinte problema de pesquisa: quais seriam as diretrizes adequadas para o desenvolvimento de conhecimento dos gestores não familiarizados em Indústria 4.0? Assim, este trabalho considera conteúdo relacionado a Indústria 4.0, gestão de negócios e Recursos Humanos e apresenta sua relevância na medida em que contribui para o desenvolvimento da Indústria 4.0 no Brasil.

Este desenvolvimento, por sua vez, ocasiona impactos sociais, ambientais e econômicos inerentes a uma revolução industrial. Especificamente em relação ao aspecto social, Bokhari; Myeong (2022); Hsu *et al.* (2019); Karajz (2021) e Morrar *et al.* (2017) demonstram que a implementação e desenvolvimento da Indústria 4.0 impacta positivamente na inovação social, estabelecida como qualquer solução nova e útil para um problema ou necessidade social que seja mais eficaz, eficiente, sustentável ou justa em relação as abordagens existentes e para a qual o valor criado (benefícios) atinja a sociedade como um todo (PHILLS; DEIGLMEIER; MILLER, 2008). Por outro lado, é importante que mencionar que a implementação da Indústria 4.0 requer transparência e planejamento a fim de minimizar a insegurança gerada no capital humano devido as mudanças requeridas, principalmente em relação à perda de emprego, atualização de habilidades, dúvidas em relação a influência positiva do desenvolvimento tecnológico e da digitalização sobre os indivíduos e a sociedade, entre outras (LUPPICINI, 2012; SONY; NAIK, 2020). Sob a ótica econômica, Masood; Sonntag (2020) consideram como principal benefício da implementação da Indústria 4.0 em pequenas e médias empresas a obtenção de vantagem competitiva, contribuindo para a eficiência, qualidade e flexibilidade de produção com redução nos custos.

1.3 Objetivo Geral e Objetivos Específicos

1.3.1 Objetivo Geral

O objetivo geral desta pesquisa se caracteriza por propor e validar diretrizes para a disseminação de conceitos relacionados à Indústria 4.0 com foco em gestores de empresas de manufatura não familiarizados aos referidos conceitos. Define-se "diretrizes" como "conjunto de normas e critérios que determinam e direcionam o desenvolvimento ou a criação de alguma coisa; procedimentos" (DIRETRIZES, 2022), e dessa forma, especificamente nessa pesquisa entende-se por "diretrizes" um conjunto de critérios que orientem a disseminação de conceitos relacionados à Indústria 4.0. Pretende-se, assim, apresentar os principais desafios e melhores práticas que podem ser adotadas para a disseminação dos mesmos, bem como propor um conteúdo validado por especialistas e agrupado em módulos temáticos. É importante mencionar que não se objetiva propor um conjunto de regras que resultem em uma trajetória pormenorizada para a disseminação de conceitos relacionados à Indústria 4.0, uma vez que exemplos, dinâmicas, e outros aspectos podem variar conforme o público em desenvolvimento.

1.3.2 Objetivos Específicos

O objetivo geral foi desmembrado em objetivos específicos, sendo os mesmos apresentados a seguir:

1) Refletir sobre os impactos da pandemia do coronavírus (COVID-19) na transição para a Indústria 4.0 no contexto do setor de manufatura brasileiro;

2) Identificar, sintetizar e classificar as principais características exploradas pelas pesquisas atuais que englobam o desenvolvimento de profissionais para a Indústria 4.0 e propor direções para pesquisas futuras;

3) Identificar os principais desafios e validar melhores práticas a serem adotadas para o desenvolvimento de conhecimentos sobre os conceitos da Indústria 4.0 em gestores que não os conhecem, mas aspiram a uma visão ampla do assunto;

4) Validar conteúdos adequados e o respectivo agrupamento dos mesmos em módulos para o desenvolvimento de conhecimentos sobre Indústria 4.0 em gestores não familiarizados a esta temática e que pretendem obter uma visão holística do mesmo.

1.3.3 Métodos Utilizados

A fim de atingir os objetivos específicos mencionados, três métodos científicos foram utilizados: revisão sistemática da literatura, método Delphi e método *Fuzzy* Delphi.

Em relação a revisão sistemática da literatura foi empregada a declaração "*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*" (PRISMA) proposta por Moher *et al.* (2009) a fim de garantir uma sistemática replicável e robusta da revisão da literatura. Trata-se de uma declaração amplamente utilizada para orientar o desenvolvimento de revisões sistemáticas da literatura em vários campos de pesquisa, incluindo o tema Indústria 4.0 (BUENO; GODINHO FILHO; FRANK, 2020; DE PAULA FERREIRA; ARMELLINI; DE SANTA-EULALIA, 2020; LIAO *et al.*, 2017). O método PRISMA consiste em um diagrama de fluxo de quatro fases (identificação, triagem, elegibilidade, inclusão) e apresenta uma lista de verificação de 27 itens para relatar uma revisão sistemática da literatura (título, resumo, introdução, métodos, resultados, discussão e financiamento) a fim de garantir a replicabilidade e robustez do processo. Posteriormente, aplicou-se a técnica de análise de conteúdo qualitativa em três fases conforme proposta por Elo; Kyngäs (2008): (a) fase de preparação; (b) fase de organização; e (c) relatar os resultados. Inicialmente, a fase de preparação (a) consiste em definir a unidade de análise a ser verificada nos documentos selecionados; a fase de organização (b) é composta por cinco etapas: codificação aberta, planilhas de codificação, agrupamento, categorização e abstração. A codificação aberta significa fazer anotações e títulos para descrever todos os aspectos do conteúdo. Depois disso, as notas e títulos são reunidos em folhas de codificação e agrupados e classificados. O objetivo é fornecer um meio de descrever o fenômeno, aumentar sua compreensão e gerar conhecimento sobre ele. A abstração considera a formulação de uma descrição geral do tema de pesquisa por meio de categorias geradas. Finalmente, no item (c), o processo de revisão e resultados são relatados com o propósito de criar uma visão geral do tema estudado.

Em relação a identificação dos principais desafios para o desenvolvimento de conhecimentos sobre os conceitos da Indústria 4.0 em gestores não familiarizados aos mesmos e validação do conteúdo adequado e o respectivo agrupamento dos mesmos em módulos foi aplicado o método Delphi. Trata-se de um método qualitativo usado para combinar sistematicamente conhecimento especializado e opiniões de um grupo de participantes e é particularmente valorizada por sua capacidade de estruturar e organizar a comunicação de um grupo de respondentes (DONOHOE; NEEDHAM, 2009; GBEDEDO; LIYANAGE, 2020). Dentre suas principais características, é um processo inclusivo, flexível e reflexivo que facilita a maneira livre e não "forçada" de debate (DONOHOE; NEEDHAM, 2009; POWELL, 2003). Uma opinião de participante, por exemplo, pode suscitar novas ideias ou debates não levantados pelos demais; a aplicação dessa técnica ocorre em "rodadas", usualmente duas ou três, sendo a primeira rodada usada para gerar ideias e questionamentos que serão utilizados nas rodadas subsequentes.

Segundo Powell (2003), o método Delphi ajuda o pesquisador a estruturar e organizar a comunicação de um grupo de participantes e é útil para situações em que julgamentos individuais devem ser usados e combinados para completar o estado de conhecimento sobre um determinado tópico. Destaca-se justamente a ideia de combinação de conhecimentos para evoluir na ciência em um campo ainda em construção, assim, as experiências dos participantes não são sobrepostas mas sim somadas. Hanafin *et al.* (2007) e Linstone (1985) argumentam que o método Delphi destaca-se por sua flexibilidade. Essa técnica pode ser utilizada em pesquisas nas quais os encontros presenciais não são possíveis devido a diferentes aspectos, ou há conflitos temporais nas agendas dos participantes. Assim, não se perde a oportunidade de consultar especialistas, mesmo que estejam em regiões diferentes e não possam participar simultaneamente (DONOHOE; NEEDHAM, 2009; POWELL, 2003).

Em relação a validação das melhores práticas a serem adotadas para o desenvolvimento de conhecimentos sobre os conceitos da Indústria 4.0 em gestores não familiarizados ao tema foi aplicado o método *Fuzzy* Delphi. É importante destacar que, nesse caso, inicialmente uma revisão sistemática da literatura possibilitou a determinação de melhores práticas a serem adotadas em treinamentos de forma geral e a referida técnica foi utilizada visando identificar as práticas válidas para o desenvolvimento de conhecimentos associados aos conceitos da Indústria 4.0. O método *Fuzzy* Delphi foi utilizado no referido cenário pois: 1) cria um melhor efeito de seleção de critérios; 2) verifica o grau de adesão a cada consenso possível; 3) respeita as opiniões originais de todos os especialistas; 4) evita que informações úteis sejam perdidas e 5) considera incertezas provenientes de informações inexatas ou insuficientes dos respondentes, sendo os algoritmos de análise dos dados projetados para minimiza-las. (KUO; CHEN, 2008; STEFANO; CASAROTTO FILHO; DUARTE, 2014).

Este método foi inicialmente proposto por Murray; Pipino; van Gigch (1985) e requer apenas uma rodada. Dessa forma, os participantes não são obrigados a modificar as suas opiniões a fim de se atingir um nível mínimo de consenso, como no método Delphi tradicional. As opiniões de todos os participantes são respeitadas e consideradas no cálculo dos graus de pertinência. A aplicação desse método inicia-se com o questionário que é respondido pelos participantes e nas etapas posteriores são feitos os cálculos para a determinação dos graus de pertinência. A partir da determinação dos graus de pertinência é possível validar as melhores práticas a serem adotadas para o desenvolvimento de conhecimentos sobre os conceitos da Indústria 4.0.

Tendo em vista os objetivos específicos e metodologias utilizadas, esta tese apresenta de forma resumida a seguinte classificação segundo os critérios acadêmicos clássicos: qualitativa, em relação à abordagem do problema; pesquisa bibliográfica em relação à estratégia de enfoque; aplicada, em relação à natureza da pesquisa; exploratória, em relação ao objetivo e questionário em relação à técnica utilizada para a coleta de dados.

Conforme Gil (2002) e Silva; Menezes (2005), a abordagem qualitativa procura descrever um fenômeno composto de vários elementos através de uma sequência de atividades, que envolve a redução dos dados, a categorização desses dados, sua interpretação e a análise de forma indutiva, sem utilizar métodos e técnicas estatísticas. Em relação a estratégia de enfoque, a pesquisa bibliográfica abrange a literatura publicada em relação ao tema de estudo a fim de que o pesquisador possa ter contato direto com o que foi escrito (GIL, 2002).

A classificação aplicada "objetiva gerar conhecimentos para aplicação prática e dirigidos à solução de problemas específicos" (SILVA; MENEZES, 2005, pg.20), ao passo que a classificação exploratório deve-se ao tema ser pouco estudado e, por meio dos resultados aqui apresentados, busca-se uma maior familiarização com o assunto e o início de um debate mais amplo que pode se fazer útil para futuras pesquisas (COOPER; SCHINDLER, 2014; GIL, 2002; TRIPODI; FELLIN; MEYER, 1975). Por fim, a coleta de dados ocorreu por meio de questionário, considerado como uma série de perguntas que devem ser respondidas pelo entrevistado por escrito sem a presença do pesquisador (ANDRADE, 1999).

1.4 Opção pela Apresentação da Tese em Formato Alternativo

Esta tese é apresentada em formato alternativo que se configura em uma sequência de quatro artigos científicos, conforme autoriza INFORMAÇÃO CCPG/UNICAMP Nº 002/2018, Art. 2ª. Assim, além desta introdução, apresenta-se os seguintes capítulos:

Capítulo 2: Neste capítulo são apresentados os artigos publicados, os quais possuem licença editorial para utilização conforme disponibilizado no Anexo 2.

1) *Potential COVID-19 impacts on the transition to Industry 4.0 in the Brazilian manufacturing sector.* Artigo publicado na revista *Kybernetes* (ISSN: 0368-492X): 2021 Journal Impact Factor = 2,352; 5 Year Impact Factor = 2,158. Este *viewpoint* apresenta reflexões sobre os impactos da pandemia do coronavírus (COVID-19) na

transição para a Indústria 4.0 no contexto do setor de manufatura brasileiro e relaciona-se com os objetivos desta tese uma vez que os tópicos essenciais a serem considerados para a disseminação de conceitos relacionados à Indústria 4.0 estão intimamente ligados ao cenário de implementação da Indústria 4.0 no Brasil;

2) *Training for Industry 4.0: a Systematic Literature Review and Directions for Future Research*. Artigo publicado na revista *Brazilian Journal of Operations & Production Management* (ISSN (Online): 2237-8960): “Emerging Sources Citation Index” em Clarivate Analytics (Web of Science Index). Este artigo tem como objetivo identificar, sintetizar e classificar as principais características exploradas pelas pesquisas atuais que englobam o desenvolvimento de conhecimento para a Indústria 4.0 conforme objetivo específico 2 apresentado na seção 1.3.2 Objetivos Específicos e propor direções para pesquisas futuras;
3) *Main Challenges and Best Practices to Be Adopted in Training for Industry 4.0*. Artigo publicado na revista *Kybernetes* (ISSN: 0368-492X): 2021 *Journal Impact Factor* = 2,352; 5 *Year Impact Factor* = 2,158. Este artigo tem como objetivo identificar os principais desafios e validar melhores práticas a serem adotadas no desenvolvimento de conhecimentos sobre os conceitos da Indústria 4.0 para gestores que não os conhecem, mas aspiram a uma visão ampla do assunto. Foi aplicado o método Delphi com a finalidade de identificar os principais desafios e o método *Fuzzy* Delphi a fim de validar as melhores práticas a serem adotadas conforme objetivo específico 3 apresentado na seção 1.3.2;
4) *Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?* Artigo publicado na revista *Technology Analysis & Strategic Management* (ISSN: 0953-7325): 2021 *Journal Impact Factor* = 3,745; *5 Year Impact Factor* = 3,571. Este artigo tem como objetivo validar conteúdos adequados e o respectivo agrupamento dos mesmos em módulos no desenvolvimento de conhecimentos em Indústria 4.0 recomendados a gestores não familiarizados com o tema e que pretendem obter uma visão holística do assunto. Foi aplicado o método Delphi junto aos especialistas na área conforme objetivo específico 4 apresentado na seção 1.3.2.

Capítulo 3: Adicionalmente às discussões apresentadas em cada artigo de maneira individualizada, este capítulo apresenta os resultados obtidos de forma conjunta, resumindo e sistematizando todas as diretrizes amplas para o desenvolvimento de conhecimento em

Indústria 4.0 e discute a relação entre as mesmas. Por fim, é apresentada a análise dos resultados obtidos considerando-se algumas das principais Teorias Gerais da Administração como a Teoria do Desenvolvimento Organizacional, Abordagem Sociotécnica, entre outras.

Capítulo 4: Neste capítulo são apresentadas as conclusões deste trabalho e são propostos vários temas para pesquisas futuras.

As referências utilizadas, as autorizações do Comitê de Ética em Pesquisa e as autorizações dos editores para uso dos artigos publicados são apresentados após o Capítulo 4.

2 ARTIGOS PUBLICADOS

Este capítulo apresenta os artigos publicados que compõem este trabalho.

O primeiro artigo intitulado "*Potential COVID-19 impacts on the transition to Industry 4.0 in the Brazilian manufacturing sector*" foi publicado na Revista *Kybernetes*. O principal objetivo deste artigo é apresentar algumas reflexões sobre a pandemia do COVID-19 impacta a transição para a Indústria 4.0 no contexto do setor manufatureiro brasileiro.

O segundo artigo intitula-se "*Training for Industry 4.0: a systematic literature review and directions for future research*" e foi publicado na Revista *Brazilian Journal of Operations & Production Management*. Este artigo tem como objetivo identificar, sintetizar e classificar as principais características exploradas pelas pesquisas atuais envolvendo treinamento e desenvolvimento para a Indústria 4.0 e propor direções para pesquisas futuras..

O terceiro artigo "*Main challenges and best practices to be adopted in management training for Industry 4.0*" foi publicado na Revista *Kybernetes* e tem como objetivo identificar os principais desafios e validar práticas para o desenvolvimento de gestores que operam no setor de manufatura, almejam uma visão ampla da Indústria 4.0 e que não estão familiarizados com os principais conceitos da mesma.

O quarto artigo, "*Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?*" encontra-se publicado na Revista *Technology Analysis & Strategic Management*. A pesquisa apresentada neste artigo propõe e valida um conteúdo adequado para o desenvolvimento de de gestores que operam no setor de manufatura, almejam uma visão ampla da Indústria 4.0 e que não estão familiarizados com os principais conceitos da mesma.

No Capítulo 3 são exploradas as conexões entre esses artigos.

Potential COVID-19 impacts on the transition to Industry 4.0 in the Brazilian manufacturing sector

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Received 24 October 2020
Revised 17 December 2020
25 January 2021
Accepted 28 January 2021

Abstract

Purpose – The purpose of this viewpoint is to present some reflections about the coronavirus disease 2019 (COVID-19) pandemic impacts on the transition to Industry 4.0 in the Brazilian manufacturing sector context.
Design/methodology/approach – Initially, a bibliographic research study was carried out to establish a theoretical background and contextualization. After analysing different kinds of documents, the authors of this viewpoint discussed potential COVID-19 impacts on the transition to Industry 4.0 in the Brazilian manufacturing sector. A multidisciplinary discursive approach was used in the debates.
Findings – The COVID-19 pandemic will negatively influence the transition of Brazilian manufacturing sector to Industry 4.0. Despite the fact that some "World Class Companies" based in Brazil still continue the transition process towards the "Digital Revolution", most of Brazilian manufacturing companies are postponing important initiatives related to Industry 4.0 due to uncertainties. In addition, policies promoting innovation are increasingly necessary.
Practical implications – This viewpoint presents interesting implications for researchers and society. Researchers can use these reflections to structure surveys or case studies to better understand the aforementioned impacts on companies due to the pandemic. These reflections can also be used by society for public policy debates. For companies, the information presented highlights the relevance of Industry 4.0 as an important phenomenon to manufacturing sector and companies' competitiveness.
Originality/value – This viewpoint presents reflections which may be used to encourage debates about how to manage digital transformation in the manufacturing sector during an unstable environment.

Keywords COVID-19, Industry 4.0, Manufacturing companies, Brazil

Paper type Viewpoint

1. Introduction

The integration of technologies in the manufacturing sector is transforming factories into smart environments, since making possible to connect information, devices and people simultaneously (Arnold *et al.*, 2016; Thoben *et al.*, 2017). This phenomenon was initially called "Industrie 4.0" by the German Federal Government, and it was expanded to another countries by the terms "Smart Manufacturing", "Industry 4.0", "Smart Industry", "Smart Factory" and

This work was supported by the Conselho Nacional de Desenvolvimento Cientıfico e Tecnologico (CNPq) under Grants 307536/2018-1 and 140998/2020-9; and Coordenačão de Aperfeičoamento de Pessoal de Nıvel Superior – Brasil (CAPES) – Finance Code 001; process 88887.464433/2019-00.

Kybernetes
Vol. 51 No. 7, 2022
pp. 2233-2239

0368-492X
DOI 10.1108/K-10-2020-0693

others (Ibarra *et al.*, 2018; Trotta and Garengo, 2018). According to Schwab (2016), the Industry 4.0 stands as a phenomenon in which emerging technologies of the physical, digital and biological worlds converge altogether to revolutionize the organization of value chains globally, disrupting business models, reshaping production, distribution, consumption and several other spheres of society and the economy.

Industry 4.0 concepts can increase factories' operational effectiveness and create totally new business models. New products and services enabled by these concepts may considerably impact countries' economies, and this justifies government engagement (Hermann *et al.*, 2016; Perini *et al.*, 2017). Specifically for emerging countries, Industry 4.0 transition should to be analysed considering two perspectives: these countries can take an advantage of digitalization process to gain efficiencies and working in a global manufacturing network that provides essential components, products and systems; however, it is important to highlight that emerging economies usually present serious challenges to adopt Industry 4.0 technologies and concepts (Cezarino *et al.*, 2019).

In parallel with this scenario, a pandemic sparked in China in March, 2020. The initial outbreak of coronavirus disease 2019 (COVID-19) occurred in the city of Wuhan, China (World Health Organization, 2020). Seven months later, the Johns Hopkins Coronavirus Resource Center reported more than 34.2 million cases globally and over 1.02 million of confirmed deaths (World Economic Forum, 2020). Brazil is the third country in the world with the highest number of confirmed cases, and it is the second country in the world with the highest number of deaths due to COVID-19 (Johns Hopkins University and Medicine, 2020). Since March 2020, the number of new cases of COVID-19 had increased considerably (Johns Hopkins University and Medicine, 2020).

The COVID-19 forced social distancing, travel restrictions, school closed down and other actions associated to self-isolation. The most part of economic sector has observed significant income losses, causing even many job losses; the need for commodities and manufactured products has decreased considerably (Nicola *et al.*, 2020). So, the way COVID-19 pandemic will directly and indirectly interfere in the Industry 4.0 implementation in emerging economies, like Brazil, is still an open research question.

In light of the above, this viewpoint aims to present some open reflections about the COVID-19 pandemic impacts on the transition to Industry 4.0 in the context of the Brazilian manufacturing sector. The Industry 4.0 concepts and the economic impact of COVID-19 pandemic are discussed, and reflections are presented. The research described by this paper is original, and a search in academic literature failed to identify any other papers with the same scope.

In addition to this introduction, the viewpoint presents more five sections. Section 2 is dedicated to present some aspects related to Industry 4.0 (with focus on emerging countries) and the Brazilian manufacturing sector; Section 3 presents methodological procedures used to structure the viewpoint; Section 4 shows the reflections of the authors; Section 5 evidences practical implications and, finally, Section 6 presents general conclusion and final considerations.

2. Industry 4.0 and the Brazilian manufacturing sector

In order to remain competitive in the Industry 4.0 context, manufacturing companies need to perform the transitions to the Industry 4.0 era putting in place important organizational changes that are extremely necessary (Ghobakhloo, 2018; Lee *et al.*, 2015). However, according to Trotta and Garengo (2018) and Wang *et al.* (2017), the Industry 4.0 concept implementation is a complex process, demanding resources, engagement, knowledge and long-term companies' vision.

The main pillars of Industry 4.0 are service orientation, smart product, smart factory, interoperability, modularity, decentralization, virtualization, real-time capability, vertical integration, horizontal integration, product personalization and corporate social responsibility (Ghobakhloo, 2018).

It is important to notice that Industry 4.0 goes only beyond technology implementation. According to Fernandes *et al.* (2019), the technology acquisition must be subordinated to its value creation. It is necessary to debate strategic direction, knowledge management, building an innovative culture and other characteristics related to the company's human capital. Among all these factors, the building of a company's culture based on the Industry 4.0 concepts is fundamental. Sony and Naik (2019) corroborate the statement present and point out the importance of disseminate Industry 4.0 concepts in all organization levels.

Many academic papers reinforce the context presented above and highlight the urgency in disseminating Industry 4.0 concepts to professionals with leadership positions. According to Brizolla *et al.* (2019), these professionals need to better understand the connection between Industry 4.0 concepts and the company's strategies. The lack of knowledge of these professionals and resistance to changes in organizational culture are the main barriers for the transition of manufacturing sector to Industry 4.0 (Benitez *et al.*, 2019; Contador *et al.*, 2020; Rocha *et al.*, 2019; Satyro *et al.*, 2019).

Considering emerging countries, investments in technologies to make companies and their production systems smart and digital are a great challenge (Cezarino *et al.*, 2019). In a survey carried out by the Industry National Confederation (CNI), it was evidenced that only 10% of Brazilian companies invested more than 8% of their investments resources in the digitalization of the processes (CNI, 2018). Another difficulty in Brazil is the availability of qualified professionals to perform activities demanded by digital processes in this new era (Cezarino *et al.*, 2019; Lima, 2017). Many challenges and difficulties observed by Brazilian companies are common for other companies in emerging economy countries; then, discussions presented in this viewpoint may also become relevant for them.

The CNI considers that Brazilian manufacturing companies are progressively familiarizing itself with Industry 4.0 concepts, and they are trying to better understand potential impacts in their business models. However, a limited knowledge about this phenomenon is considered a major obstacle for its implementation and development (CNI, 2016a). In a study considering a sample of 2,225 manufacturers companies located in Brazil (41% small manufacturers, 37% medium manufacturers and 22% large manufacturers), 935 companies reported not being able to recognize the importance of digital technologies for industry competitiveness (CNI, 2018).

Another important study carried out by the São Paulo Industries Federation (FIESP) provides interesting insights about the Brazilian context. In this study, a survey with 227 manufacturing companies was performed (55% small industries, 30% medium industries and 15% large industries). Results revealed that 73 companies (almost a third) do not know the term "Fourth Industrial Revolution", "Industry 4.0" or "Advanced Manufacturing" (FIESP, 2018). This is a challenging scenario for policymakers and decision-makers.

Focusing on the Sorocaba Metropolitan Region (a group of 27 cities in the São Paulo State), Firmino *et al.* (2020) carried out another survey with 47 manufacturing companies. Results evidenced that the expression "cyber-physical system" (CPS) was one of the least known terms by the participants although the abundant literature in the field. Firmino *et al.* (2020) also analysed the companies' technological level and the result suggest that, on average, the surveyed companies are still living a transition from the second to the third industrial revolution.

Considering the context mention above, it is possible to note that there are many Brazilian companies without basic knowledge concerning Industry 4.0, evidencing the importance of this theme to the academic and the public policies (FIESP, 2018; Firmino *et al.*, 2020).

3. Methodological procedures

The first stage to structure this viewpoint was carried out a bibliographic research study, in order to establish a theoretical background and contextualization. The following scientific bases were accessed: Scopus, Elsevier, Emerald, Web of Science, Wiley and Periódico Capes (a Brazilian scientific database) using the following strings: ("COVID-19" OR "coronavirus") AND ("Industry 4.0" OR "Industrie 4.0" OR "digital manufacturing" OR "cyber physical system") AND ("Brazil"). Magazine papers, economic reports, industrial reports and economic outlooks were also included in this research.

After analysing different kinds of documents, the authors of this viewpoint discussed the potential COVID-19 impacts on the transition to Industry 4.0 considering the Brazilian manufacturing sector. Following a multidisciplinary discursive approach, different arguments were debated considering authors' knowledge and their experience in the mentioned sector.

Considering methodological criteria to classify academic studies, this viewpoint presents a qualitative and applied approach. No statistical techniques were used to analyse data, and the main objective can be classified as exploratory. The classifications mentioned are in a accordance to several authors (Andrade, 1999; Gil, 2002; Godoy, 1995; Gray, 2018; Lakatos and Marconi, 2003; Malhotra, 2012; Silva and Menezes, 2005).

4. Results of the debates

Based on the bibliographic research carried out and procedures mentioned in previous section, the results were obtained, and they are presented in this section. It is possible to observe different levels of COVID-19 impacts on Industry 4.0 transition considering the Brazilian manufacturing sector, and our reflections will be divided according these levels.

There are a few numbers of manufacturing companies that will continue to invest in Industry 4.0 projects aiming more productivity and competitiveness despite the economic crisis. They have resources (mainly financial and human) to withstand the COVID-19 pandemic impacts, and they will maintain their strategies towards digitalization. The WEG, a large Brazilian company operating in the electric engineering, power and automation, is one example of company inserted in these conditions. It is considered a world-class company and has a prominent place in the Brazilian manufacturing sector. According to Fucuchima (2020), since last year, this company structured a specific area dedicated to centralize digitalization projects already started in different business segments of the company. This dedicated area executed a series of start-up's acquisitions in order to improve the WEG digitalization movement. Even with the pandemic, WEG continued its efforts to no stop projects of digitization processes and products.

However, it is not the reality for many other Brazilian manufacturing companies as presented by CNI (2016a, b, 2018), FIESP (2018) and Firmino *et al.* (2020). Most Brazilian companies survive in a different context (Schumpeter, 2015). Mainly, the small and medium enterprises (SMEs) were initializing the understanding about Industry 4.0 and planning some small initiatives in this field when the COVID-19 pandemic crisis started. To face this new scenario, which includes activity paralysis and uncertainties about the next actions and conditions, many Brazilian manufacturing sector businessmen discontinued investments and related activities outside their core ones when the economic instability was just noted. They postponed most of the initiatives associated to Industry 4.0, including planning, implementation and employees training.

This implies that several Brazilian manufacturing companies will only return to discuss any kind of Industry 4.0-related technology investments after an economic stability period. This moment may be observed in five years from now or more, but it is not possible to forecast. In this case, some of the little progress towards digital evolution that been achieved so far may be completely lost or at least hindered. This kind of mismatches towards digital transformation may lead some companies to critical situations in the future (Ananyin *et al.*, 2018; Cohen and Tripsas, 2018; Day and Schoemaker, 2016).

Finally, it is important to notice that a large number of Brazilian manufacturing companies do not even know the basic definitions regarding the terms "Industry 4.0", "Digital revolution" and their associated technologies, and considering its importance in the implementation of Industry 4.0 practices in Brazilian companies as presented in the section "2 Industry 4.0 and the Brazilian Manufacturing Sector", it calls for an urgent governmental action. A more forward-thinking innovation and industry public policies should encourage knowledge dissemination, favour more intensive debates and support manufacturing transformation.

5. Implications

The reflections presented in the previous section have interesting implications. Considering academic field, researchers can use these reflections to structure surveys or case studies with companies in order to better understand the mentioned impacts due to the pandemic. As an example, studies can be performed considering companies' size, different economic sectors, need for an employee's qualification, among other topics. The reflections can also be used by society to debate with its governmental representatives' policies for industrial sectors, workers capacitation programs and employment generation. For companies, the information shows the relevance of Industry 4.0 as an important phenomenon to the manufacturing sector and competitiveness of enterprises.

6. Conclusions and final considerations

Considering the arguments presented in the previous section, we support that the COVID-19 pandemic crisis will significantly delay the transition of the Brazilian manufacturing sector towards the Digital Revolution. Those enterprises classified as world-class companies will continue their projects and organizational changes; however, for the most part of manufacturing companies' sector, the COVID-19 pandemic will postpone all kinds of initiatives. There are still those businessmen who do not even know terms like "Industry 4.0" and "Digital revolution" and their associated technologies. In this case, public policies promoting innovation and training would be outstandingly valuable.

It is evident that this viewpoint represents the opinion of its authors, and this may be understood as a limitation; however, we emphasize that the opinions presented in the text were structured after paper and report analyses and several debates. Also, authors' experience in Brazilian manufacturing sector analysis is emphasized. As a future study, we suggest the realization of panels' experts with participants from different emerging economies countries to better understand the COVID-19 impacts in Industry 4.0 projects.

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Brazilian Journal of Operations & Production Management
ISSN 2237-8960 (Online)
ABEPRO ASSOCIAÇÃO BRASILEIRA DE ENGENHARIA DE PRODUÇÃO

LITERATURE REVIEW

Training for Industry 4.0: a systematic literature review and directions for future research

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How to cite: Cazeri, G.T., Santa-Eulalia, L.A., Serafim, M.P. et al. (2022), "Training for Industry 4.0: a systematic literature review and directions for future research", *Brazilian Journal of Operations & Production Management*, Vol. 19, No. 3, e20221355. https://doi.org/10.14488/BJOPM.2022.007

ABSTRACT

Goal: This study aims to identify, synthesize and classify the main features explored by current research encompassing training for Industry 4.0 and propose directions for future research.

Design / Methodology / Approach: The methodological procedure was oriented by a systematic literature review (PRISMA) methodology and followed by content analysis. After a review of academic databases, 78 papers dealing with training for Industry 4.0 were included and classified based on topics related to the science of training and Industry 4.0.

Results: Most of the studies in training for Industry 4.0 are oriented to undergraduate and graduate students (in an educational approach) or industrial employees (in an enterprise approach) and, in general, they explore technical, technological, and human-oriented subjects. There is a lack concerning studies targeting managers who deal with Industry 4.0 and few studies consider content related to Industry 4.0 impact on business models, sustainability, corporate social responsibility, and other related concepts.

Limitations of the investigation: The main limitation is related to the database selection criteria. Search in non-indexed databases, book chapters, and non-English language are not included in this study.

Practical Implications: The findings presented in this paper are relevant for researchers and academics as they can serve as a guide for future research work. Consultants, professionals, and trainers can enhance their courses by including currently less explored content or target audiences.

Originality/Value: No similar papers were found in scientific databases and this reinforces this manuscript's originality and contribution.

Keywords: Industry 4.0; Training; Human Resource Management; Knowledge transfer.

1. INTRODUCTION

There is a new stage in developing production systems which presents as one of its pillars the digitalization of processes in the manufacturing environment designated as "Industry 4.0" at Hannover Fair in 2011. It is related to different terms as "Internet of Things", "Cyber-physical systems", "Smart Manufacturing", "Big Data" and "Smart Factory" (Benitez et al., 2019; Ghobakhloo, 2018; Trotta and Garengo, 2018). The relevance of Industry 4.0 and its implementation is based mainly on the possibility of increasing profitability in industrial production and, consequently, raising organizational performance (Brunheroto et al., 2021;

Financial support: This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under the grants 140998/2020-9 and 304145/2021-1.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: gustavo_tietz@yahoo.com.br
Received: 31 Oct 2021.
Approved: 22 Feb 2022.
Editor: Julio Vieira Neto.

Rojko, 2017). In addition to favoring cost reduction, Rojko (2017) also mentions other benefits associated with the adoption of Industry 4.0 concepts, such as, shorter time-to-market for the new products, more flexible and friendlier working environment, custom mass production without significantly increasing overall production costs, more efficient use of natural resources and energy, and others (Bai et al., 2020; Brozzi et al., 2020; Masood and Sonntag, 2020; Oztemel and Gursev, 2020; Zhong et al., 2017).

Due to these potential benefits, the implementation of Industry 4.0 concepts is being pursued by companies, especially in the manufacturing sector. According to Sony and Naik (2019), understanding Critical Success Factors is essential for this endeavor and three of them are linked to people: aligning Industry 4.0 initiatives with organizational strategy; unconditional support from senior management for Industry 4.0 initiatives, and the importance of employees for the success of Industry 4.0. Regarding the importance of employees for the success of Industry 4.0, Cerezo-Narváez et al. (2017); Dos Santos and Benneworth (2019); Schallock et al. (2018) highlight the relevance of training to provide the necessary competencies to the projects to be carried out.

According to Salas et al. (2012), "there is a science of training that shows that there is a right way and a wrong way to design, deliver, and implement a training program". It has a long tradition dating back to the early 1900s and it is a science with a legacy of evolution and with significant studies capable of promoting effective learning and positive results (Bell et al., 2017). According to the science of training, there are some key characteristics with a marked influence on the knowledge transfer that have to be considered when designing and delivering a training program, including: target audience, organizational conditions in which the training is offered, training content, pedagogical approach, learning methodology, and use of techniques to motivate participants (Kodwani, 2017; Massenberg et al., 2016, 2015; Salas et al., 2012, 2015; Sanna Junior and Goshorn, 2017; Tews and Noe, 2019).

In the training's plan phase, it is important to collect information about participants and analyze the profile of the group considering issues related to diversity, expectations, and requirements (Cheng et al., 2019; Li et al., 2019; Yang et al., 2018a). In addition, the training content is an important key characteristic as it influences the participant's motivation and, consequently, the knowledge transfer. The training content must be based both on the main theme to be learned by the participants and also based on the participant's profile (Salas and Cannon-bowers, 2001; Taylor and Bisson, 2019; Tian et al., 2015).

Despite the relevance of training for Industry 4.0 (Cerezo-Narváez et al., 2017; Schallock et al., 2018; Sony and Naik, 2019) and the growing number of papers that have been published about Industry 4.0 since 2011 (Pereira et al., 2018), it is still unclear within academia what the main characteristics explored by the researches dealing with training for Industry 4.0. We found no research paper that provides a review of this topic, specifically. Thus, this paper provides a literature review for a better understanding of the state of the art regarding the subject "training for Industry 4.0" and aims to answer the following three specific research questions: 1) As the target audience is a key characteristic on the knowledge transfer, does current research explore every target audience on training for Industry 4.0?; 2) As content is a key characteristic in knowledge transfer, does current research explore all the content on training for Industry 4.0?; and 3) What are the training approaches currently being explored?

Besides this introduction, this paper has five additional sections. Section 2. Theoretical Background details the theoretical basis regarding Industry 4.0 training and the science of training. Section 3. Methodological Procedures presents the details to allow the replicability of this research, Section 4. Results details the results obtained considering the application of methodological procedures, Section 5. Discussions discusses the results presented in Section 4, while Section 6. Conclusion presents the main conclusions and suggests some future research.

2. THEORETICAL BACKGROUND

Industry 4.0 and Training

Industry 4.0 aims to combine production agents (machines, robots, and operators) through a network of connections and information management based on three main factors: technology, organization, and human factors (Ardito et al., 2019; Dregger et al., 2016; Ghobakhloo, 2018, 2020; Hermann et al., 2016; Oztemel and Gursev, 2020; Reuter et al., 2017).

Considering specifically the human factor, the biggest threat to the implementation of Industry 4.0 is related to the resistance of workers to adopt new technologies and the need for training presents itself as the biggest weakness (Jain et al., 2021). Thus, training and continuous professional development deserve special attention and importance for Industry 4.0 (Kaya et al., 2020; Schallock et al., 2018). Especially for manufacturing companies, Bakhtari et al. (2021) present the lack of leadership from the management, lack of skills for training and education programs, and lack of qualified workforce as the main challenges in implementing Industry 4.0.

Nowadays, learning factories are effective for developing theoretical and practical training in a real production environment for undergraduates, graduate students, and workers (Abele et al., 2017; Baena et al., 2017). Learning factories can train technical and social skills; for example, installing and operating IT devices such as RFID tags, tablets, automatic guided vehicles, and others, proposing and realizing changes in all stages of the production system, practicing teamwork, knowledge transfer, knowledge acquiring, collaboration for synchronization of processes, and others. Specifically for undergraduate and graduate students, it is important to prepare them for real situations they will face in the future in both the technical and social aspects. (Baena et al., 2017; Schallock et al., 2018; Wienbruch et al., 2018).

Kim et al. (2020) proposes a cyber learning factory for operations management developed by applying 3D factory simulation software which can be used to train both operations managers of manufacturing companies and information systems architects of Information Technologies companies in a technical approach. According to Helming et al. *(*2019), managers play a crucial role in leading the implementation and development of Industry 4.0 in a company. Sony and Naik (2019) consider the performance of managers as one of the ten critical success factors in implementing Industry 4.0.

In addition to the technical and social skills developed in the training provided by the learning factories, several authors reinforce the importance of discussing the impact of Industry 4.0 on business models and other related concepts such as sustainability, CSR, lean, and others. Machado et al. (2020) presents opportunities for sustainable manufacturing in Industry 4.0 on the reduction of waste, energy consumption, and overproduction; creating job opportunities related to Information Technologies competencies and improving quality of working environment reducing routine jobs; Stock and Seliger (2016) presents a practical case of manufacturing equipment retrofitting as a specific opportunity for sustainable manufacturing in Industry 4.0; Nascimento et al. (2019) explore how rising technologies from Industry 4.0 can be integrated with circular economy (CE) practices to establish a business model that reuses and recycles wasted material such as scrap metal or e-waste and Potočan et al. (2021) reports about research on how Society 5.0 balances Industry 4.0, responsible economic development and resolution of social problems by the advancement of corporate social responsibility (CSR) in organizations.

Finally, the digital aspect of Industry 4.0 has been introduced in training with the use of technologies such as virtual simulations and gamification. Vidal-Balea et al. (2020a) proposes an augmented reality framework to facilitate, support, and optimize production and assembly tasks through training and assistance; Carretero et al. (2021) presents a methodology to develop virtual reality tutorials and training courses for professional preparation in industrial jobs, and Ulmer et al. (2020) proposes a novel concept and evaluation system combining gamification and virtual reality practice for flexible assembly tasks. These virtual simulations and gamification consider learning based on the presentation and discussion of situations experienced in practice and, due to this characteristic, it is considered a practical training approach. It is important to mention that introduction of the digital aspect in Industry 4.0 training aims to optimize knowledge transfer and improve training participants' learning.

Science of Training

On the other hand, there is a science of training that studies the best practices to be adopted in training to optimize the transfer of knowledge and participants' learning. Based on Bell et al. (2017); Cheng et al. *(*2019); Salas et al. (2012, 2015) and Yang et al. *(*2018a), target audience, training content, and training approach are key factors that should be considered when planning and designing training.

Information and data about the target audience must be collected and made known before the training is applied, that is, in the pre-training phase. According to Salas et al., (2012, 2015) and Yang et al. (2018a), in the pre-training phase a diagnosis is made of what needs to be trained (content) and for whom the training is intended (target audience) to enable the preparation of the next training phases (training and post-training) properly as guiding training design, presenting expected learning outcomes, and guiding training evaluation.

The training approach focuses on applying appropriate instructional strategies and outlining content and should be considered during the training phase (Salas et al., 2012, 2015; Sanna Junior and Goshorn, 2017). Regarding instructional strategies, it considers the following basic principles: (a) inform: present information or relevant concepts to be learned; (b) demonstrate: demonstrate knowledge, skills, and attitudes (KSAs) to be learned; (c) practice: create opportunities for participants to practice skills and; (d) provide feedback: reporting to participants during the training phase and in the post-training phase (Bell and Kozlowski, 2008; Salas and Cannon-bowers, 2001; Taylor and Bisson, 2019; Tian et al., 2015). In connection with these basic principles, an active learning methodology such as Project or Problem-based Learning (PBL) presents two main characteristics: (a) it provides the participant with responsibility for important decisions regarding the learning process, such as the choice of learning activities and monitoring and judging the progress of their own learning; (b) promote an inductive learning process, in which participants explore and experience a given task in order to infer its rules, principles and strategies for effective performance. Specifically, in relation to PBL, it should be considered that scientific research and psychological theory demonstrate that training participants simultaneously learn content and thinking strategies by learning from problem-solving experiences (Bell et al., 2017; Piñol et al., 2017; Salas et al., 2012, 2015; Stankunas et al., 2016; Werth, 2011)

Figure 1 presents an analytical framework organizing key topics related to the science of training and Industry 4.0, thus guiding the research questions of this study and the systematic literature review that will be presented in the next sections.

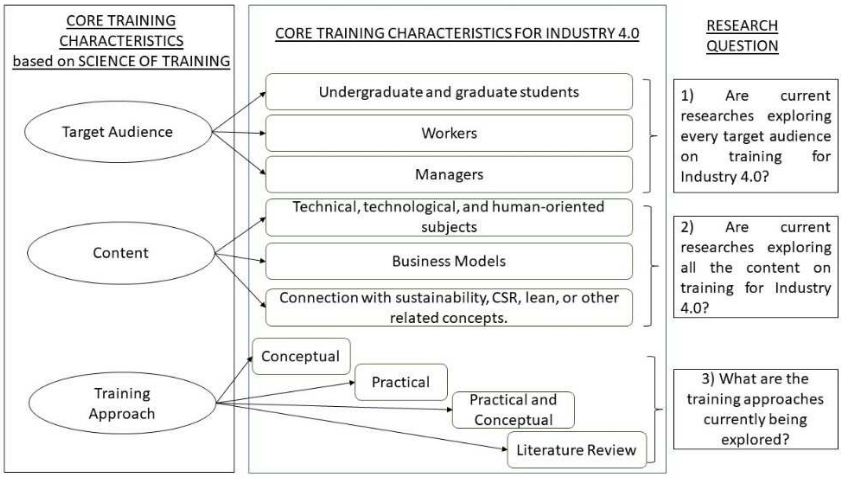

Figure 1. Analytical Framework.
Source: The authors themselves

3. METHODOLOGICAL PROCEDURES

In order to answer the three research questions mentioned above, a methodological procedure was elaborated based on three stages and followed step-by-step to allow the replicability of this research. Figure 2 presents a methodological framework to facilitate the presentation and understanding of the stages developed.

In stage 1, the preferred reporting items for systematic review and meta-analysis (PRISMA) methodology (Moher et al., 2009) oriented the research to ensure a replicable and robust systematic literature review. This methodology is widely used to guide the development of systematic literature reviews in various research fields, including the Industry 4.0 subject (Bueno et al., 2020; Liao et al., 2017; de Paula Ferreira et al., 2020).

The PRISMA methodology consists of a four-phase flow diagram (identification, screening, eligibility, inclusion), and the input data and results obtained in each phase are shown in Figure 1. The PRISMA methodology also presents a 27-item checklist to report a systematic literature review (title, abstract, introduction, methods, results, discussion, and funding) and it supported the development of all sections of this research.

Stage 2 consisted of qualitative content analysis based on Elo and Kyngäs (2008). According to them, a content analysis must be performed in three phases: (a) preparation phase; (b) organizing phase; and (c) reporting the results. This last item is presented in stage 3.

During the preparation phase (a), the unit of analysis must be defined. Specific for this research, the unit of analysis was defined as a theme: "main characteristics explored by researches on training for Industry 4.0". The organizing phase (b) was composed of five steps: open coding, coding sheets, grouping, categorization, and abstraction. Open coding means taking notes and headings to describe all aspects of the content. After this, the notes and headings are collected onto coding sheets and grouped and classified. The purpose is to provide a means of describing the phenomenon, to increase understanding, and to generate knowledge about it. Abstraction considers the formulation of a general description of the research topic through generated categories. Finally, in the (c) reporting the review process and results, an attempt is made to create an overview of the topic studied.

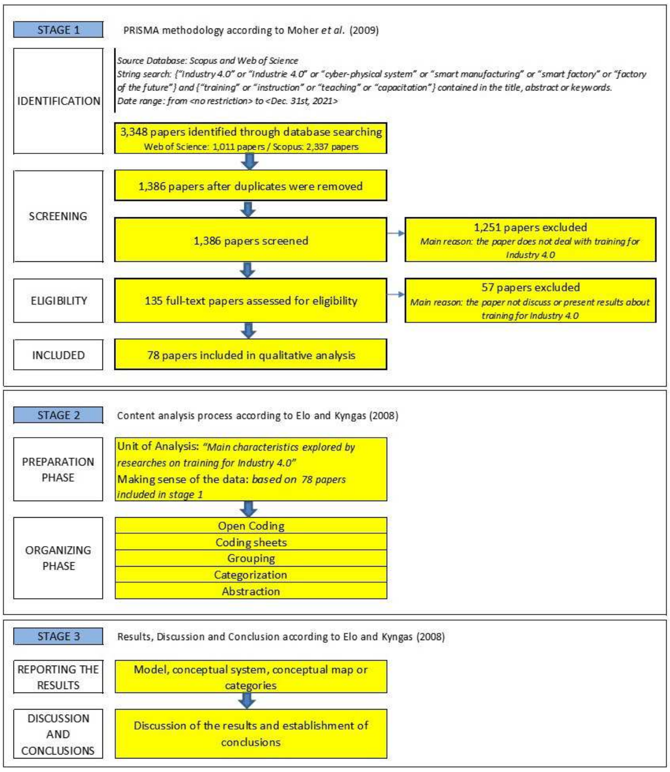

Figure 2. Methodological Framework.
Source: The authors themselves

Based on the above-mentioned procedures, the following (3) three categories were created based on the science of training (Cheng et al., 2019; Kodwani, 2017; Salas et al., 2012, 2015; Yang et al., 2018b) to group and categorize the 78 papers included in stage 1 of the methodological framework (see Figure 1): target audience, training content, and training approach.

Concerning target audience classification, Table 1 shows the categories used to group the analyzed papers. As mentioned previously, the main characteristics of participants must be known by the trainer and it is essential to prepare good content and, consequently, obtain success in knowledge transfer (Bell et al., 2017; Salas et al., 2012, 2015).

Table 1. Categories used to classify papers based on the target audience

Target Audience	Description
Undergraduate and graduate students	Industry 4.0 training aimed at students in graduation or postgraduation;
Workers	Industry 4.0 training aimed at employees in different stages of company production;
Managers	Industry 4.0 training aimed at employers, managers, or executive officers.

Source: The authors themselves

Regarding training content, papers were grouped into categories presented in Table 2.

Table 2. Categories used to classify papers based on training content

Training Content	Description
Industry 4.0 technical, technological, and human-oriented subjects	Discuss training content related to Industry 4.0 aspects as pillars and principles, robotics, robots, smart factory, production planning, a new way of production, maturity, cases of success, new competencies, and others;
Industry 4.0 and Business Models	Discuss training content related to new business models generated by Industry 4.0 or current business models impacted by Industry 4.0;
Industry 4.0 and other concepts connection	Discuss training content related to the impact or connection between Industry 4.0 and sustainability, CSR, lean, or other related concepts.

Source: The authors themselves

Finally, the papers were classified according to training approach. Table 3 shows the categories used for training approach classification and presents a description of each category.

Table 3. Categories used to classify papers based on training approach

Research Type	Description
1. Conceptual	Discuss training approach theoretically;
2. Practical and Conceptual	Discuss training approach theoretically and present applications and practical examples related to theory;
3. Practical	Discuss training approach with only applications or practical examples;
4. Literature Review	Perform a literature review on training for Industry 4.0 theme.

Source: The authors themselves

After the description of the results, discussions were done and conclusions were established.

4. RESULTS

The 78 published papers included in stage 1 of the methodological framework (see Figure 1) were sorted by date and Figure 3 shows the results. It is important to mention that no restriction was considered for the initial date of the published papers, so the first paper available in the Web of Science and Scopus database is from the year 2015. The expressive growth of the number of published papers in the last years compared to previous years is consonant with the growing search for the implementation of Industry 4.0 (Cordeiro et al., 2019; Frank et al., 2019; Ghobakhloo, 2018).

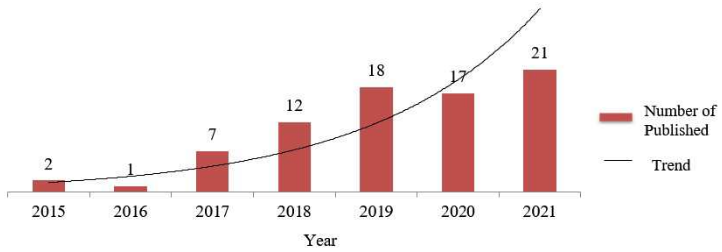

Figure 3. Distribution of published papers per year.
Source: The authors themselves

In the sequence, these 78 published papers were classified according to Table 1, Table 2, and Table 3 and the result is presented in Figure 4, Figure 5, and Figure 6, respectively. The Appendix A presents the classification individualized by paper.

Based on Figure 4, it can be noted that almost all research on training for Industry 4.0 focuses on students and workers as their target audience and a gap is observed about managers as their target audience. Figure 5 presents research on training for Industry 4.0 focusing essentially on the technical, technological, and/or human-oriented subjects and a gap in addressing content about the impact of Industry 4.0 in business models and the relationship of Industry 4.0 with sustainability, CSR, and other concepts.

Figure 6 shows the larger amount of research deals with the conceptual and practical application of Industry 4.0 concepts, that is, discusses training approach theoretically and presents applications and practical examples related to theory. On the other hand, no papers considered literature review on training for Industry 4.0.

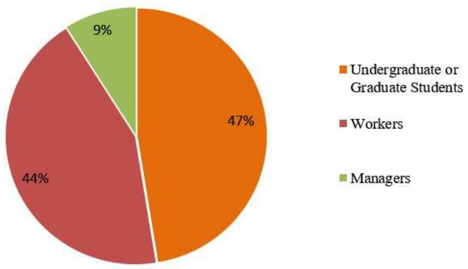

Figure 4. Distribution of papers according to the target audience.
Source: The authors themselves

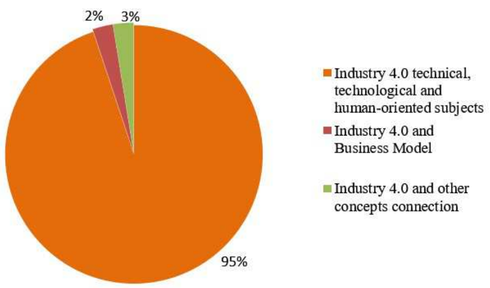

Figure 5. Distribution of papers according to training content.
Source: The authors themselves

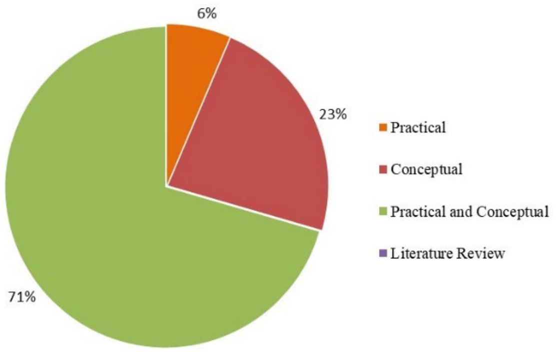

Figure 6. Distribution of papers according to training approach.
Source: The authors themselves

Figure 7 presents the results in a consolidated form. The majority of research is focused on undergraduate, graduate students, and workers with technical, technological, and human-oriented content. Research gaps are for research in management training including content related to the impact of Industry 4.0 on business models, sustainability, CSR, lean, and other related concepts. The conceptual and practical approach is the most applied in research and there is a gap related to literature review.

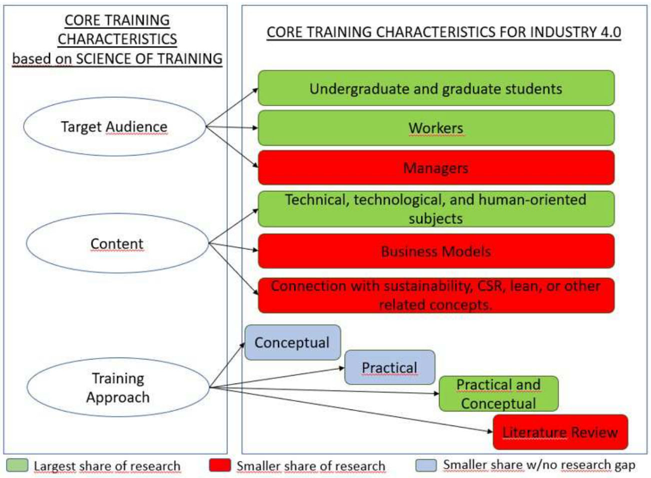

Figure 7. Share of research regarding training for Industry 4.0.
Source: The authors themselves

5. DISCUSSION

Given that the majority of research in training for Industry 4.0 has students and workers as their target audience, it is possible to notice the effort that educational institutions and companies have been making to prepare students and the current workforce for future professional challenges.

However, a gap can be observed about managers as the target audience. Based on Helming et al. (2019) and Moeuf et al. *(*2018), managers are one major component for Industry 4.0 implementation and they have a prominent role in the success and/or failure of an Industry 4.0 project; Sony and Naik (2019) consider managers as the seventh critical factor for Industry 4.0 implementation. Thus, managers are an important target audience that should be included in research about training for Industry 4.0.

Considering the training content, research on training for Industry 4.0 focuses essentially on the technical, technological, and/or human-oriented subjects. It is a relevant topic considering the new hard and soft skills required by Industry 4.0, especially for students and workers (Cerezo-Narváez et al., 2017; Dos Santos and Benneworth, 2019; Schallock et al., 2018; Sony and Naik, 2019).

Nevertheless, there is a gap in addressing content about the impact of Industry 4.0 in business models and the relationship of Industry 4.0 with sustainability, CSR, and other concepts. The importance of this theme is presented by several researchers, among them Müller et al. (2018) that analyses how Industry 4.0 triggers changes in the business models of small and medium German manufacturing enterprises; Wagire et al. (2020) concludes that innovative business models are one of the main pillars of Industry 4.0 and have a notable function in digital transformation and Arnold et al. (2016) and Ibarra et al. (2018) present a literature review on how Industry 4.0 affects business models. De Sousa Jabbour et al. (2018) argues that Industry 4.0 has the special potential to unlock environmentally-sustainable manufacturing; Ghobakhloo (2020) identifies the sustainability functions of Industry 4.0 and Sony and Naik (2019) consider sustainability the tenth critical success factor for Industry 4.0 implementation.

Taking into account the training approach, the majority of the research deals with the conceptual and practical application of Industry 4.0 concepts and it is aligned with an active learning methodology such as Project or Problem-based Learning (PBL) (Bell et al., 2017; Piñol et al., 2017; Salas et al., 2012, 2015) and with the application of new technologies such as virtual reality, augmented reality, insertion of robots in the production line, insertion of technology for planning production lines, and others (Carretero et al., 2021; Ulmer et al., 2020; Vidal-Balea et al., 2020b). In contrast, literature review papers take an essential role on an emergent and unexplored subject like training for Industry 4.0, showing an up-to-date scenario, identifying gaps, and proposing directions for future research.

Based on the combination of the results presented in Figure 4 and Figure 5, it can be noted that undergraduate students, graduate students, and workers receive essentially technical, technological, and human-oriented knowledge in training for Industry 4.0. On the other hand, it is necessary to explore Industry 4.0 training aimed at managers and consequently, explore training content regarding Industry 4.0 impact on business models and other concepts such as sustainability and CSR, once knowledge about its content is essential for the performance of the managerial role.

6. CONCLUSIONS

The general purpose of this study is to identify, synthesize, and classify the main features explored by current research encompassing training for Industry 4.0 and propose directions for further research. Based on the results, it was possible to answer the three specific research questions.

The search on academic bases has enabled the finding of seventy-eight papers, which were analyzed and classified into the target audience, training content, and research type. Most of the papers are directed to undergraduate students, graduate students, and workers and deal with technical, technological, and human-oriented subjects related to Industry 4.0. The majority of the papers present conceptual and practical or only conceptual approaches and no paper performed a literature review about training for Industry 4.0.

There is a gap concerning managers as the target audience according to our findings. Managers are required to be capable of guiding the change to Industry 4.0 by handing over the correct vision, creating the proper culture, and making the proper alliances within the organization. Industry 4.0 requires prepared leadership capable of leading and motivating employees towards a common goal (Helming et al., 2019; Moeuf et al., 2018; Sony and Naik, 2019). Thus, future research agenda on training for Industry 4.0 can focus on managers as target audience as well a future research avenue can explore the disposal and availability of managers to engage in training for Industry 4.0 compared to the training availability. Such surveys may even consider case studies and industry surveys.

Regarding the training content, there is a need to explore a holistic view of Industry 4.0 considering aspects of business models, sustainability, CSR, among others. Rojko (2017) cites the efficient use of natural resources and energy as an example of benefit associated with

Industry 4.0 implementation and connected with sustainability. Business models are impacted by Industry 4.0 and innovative ones are necessary for Industry 4.0 implementation (Arnold et al., 2016; Ibarra et al., 2018; Müller et al., 2018; Wagire et al., 2020). Thus, content related to business models and sustainability must be included in a research agenda proposal for Industry 4.0 training. It is noteworthy that literature review research should follow the development of Industry 4.0 training subject and this paper intends to make a first contribution to this topic.

It is important to notice that papers about Industry 4.0 managers training which is performed and reported in non-academic databases, namely "grey literature", are not included in this study and it is a limitation of the investigation. An analysis including these additional databases may lead to different results and it is a proposal for future research about Industry 4.0 managers' training.

It is expected that the above findings contribute to the improvement of the current state of knowledge about training for Industry 4.0 and they become used by researchers or trainers to boost their courses.

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Author contributions: Research Coordination: RA, LASE; Research Conception and Design: RA, LASE, GTC; Assistance in research planning: MPS; Data Collection: GTC; Analysis and Interpretation of results: GTC; Text writing: GTC; Textual Review: RA, LASE, MPS, GTC.

APPENDIX A. CLASSIFICATION INDIVIDUALIZED BY PAPER

Item	Reference	Classification acc. Table 1 (target audience)	Classification acc. Table 2 (training content)	Classification acc. Table 3 (research type)
1	(Faller and Feldmúller, 2015)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
2	(Lin et al., 2015)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
3	(Abed et al., 2016)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
4	(Bueno-Delgado et al., 2017)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
5	(Gorecky et al., 2017)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
6	(Perini et al., 2017b)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
7	(Perini et al., 2017a)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
8	(Piñol et al., 2017)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
9	(Schroeder et al., 2017)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
10	(Vila et al., 2017)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
11	(Ahmad et al., 2018)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
12	(Büth et al., 2018)	Workers	Industry 4.0 and other concepts connection	Practical and Conceptual
13	(ElMoaqet et al., 2018)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
14	(Horrillo Tello and Triado Aymerich, 2018)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
15	(Huang, 2018)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
16	(Koleva and Andreev, 2018)	Managers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
17	(Mortensen and Madsen, 2018)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
18	(Mourtzis et al., 2018)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
19	(Schallock et al., 2018)	Managers	Industry 4.0 and other concepts connection	Practical and Conceptual
20	(Schrack, 2018)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
21	(Yang et al., 2018a)	Managers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
22	(Żywicki et al., 2018)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
23	(Abidi et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
24	(Bayes and Iglesias, 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
25	(Bogoviz et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
26	(Buligina and Sloka, 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
27	(Gerasimova et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
28	(Heinz et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
29	(Helming et al., 2019)	Managers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
30	(Longo et al., 2019)	Managers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual

APPENDIX A. CONTINUED...

Item	Reference	Classification acc. Table 1 (target audience)	Classification acc. Table 2 (training content)	Classification acc. Table 3 (research type)
31	(Moica et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
32	(Myznikova et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 and Business Model	Conceptual
33	(Pérez et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
34	(Roldán et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
35	(Saorín et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
36	(Segura et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
37	(Strubelt et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
38	(Tosello et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical
39	(Tran et al., 2019)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
40	(Tsourma et al., 2019)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
41	(Beloglazov et al., 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
42	(Cardillo and Chacon, 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
43	(Casillo et al., 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
44	(Jovanovic et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
45	(Kans et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
46	(Karbach et al., 2020)	Managers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
47	(Malaga and Ulrych, 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
48	(Mingaleva and Vukovic, 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
49	(Molino et al., 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
50	(Oleskow-Szlapka et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
51	(Segura et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical
52	(Silva et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
53	(Tovar et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
54	(Ulmer et al., 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
55	(Vidal-Balea et al., 2020a)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
56	(Yuanlong et al., 2020)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Conceptual
57	(Zawadzki et al., 2020)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
58	(Azevedo and Almeida, 2021)	Managers	Industry 4.0 and Business Model	Practical and Conceptual
59	(Benis et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
60	(Caño de las Heras et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
61	(Carretero et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
62	(de Giorgio et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual

APPENDIX A. CONTINUED...

Item	Reference	Classification acc. Table 1 (target audience)	Classification acc. Table 2 (training content)	Classification acc. Table 3 (research type)
63	(Dhalmahapatra et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
64	(Dobrilovic et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
65	(Gutiérrez-Martínez et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
66	(Hernández-Chávez et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
67	(Matulis and Harvey, 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
68	(Paszkiewicz et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
69	(Wang et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
70	(Židek et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
71	(Kliment et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical
72	(Mäkiö et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
73	(Simões et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical
74	(Tihinen et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical
75	(Lopez et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
76	(Romero-Gazquez et al., 2021)	Workers	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
77	(Hernández-Chávez et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual
78	(Muthukumar et al., 2021)	Undergraduate or Graduate Students	Industry 4.0 technical, technological and human-oriented subjects	Practical and Conceptual

Source: The authors themselves

Main challenges and best practices to be adopted in management training for Industry 4.0

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Received 11 March 2022
Revised 15 June 2022
Accepted 28 July 2022

Abstract

Purpose – The objectives of this study are twofold: identify the main challenges in performing training on Industry 4.0 concepts to managers operating in the manufacturing sector who are not familiar with them but aspire for an Industry 4.0 broad view and validate training practices that can be adopted to reduce managerial knowledge differences.

Design/methodology/approach – A Delphi method was carried out in two rounds to identify the Industry 4.0 training challenges and a Fuzzy Delphi method was applied in one round to validate the training practices. Both methods used the same set of participants composed of experts in training for Industry 4.0. Results were discussed considering literature statements.

Findings – In total, 11 challenges in Industry 4.0 training were identified and grouped into: challenges associated with the necessary knowledge, challenges of breaking paradigm, challenges associated with training characteristics and challenges associated with expected results. In total, 11 training practices were directly validated, including actions to be adopted before, during, and after the training process.

Originality/value – The findings are relevant for professionals, academics, or consultants as the findings enable better training planning and execution. No similar papers were found in scientific databases, reinforcing this present study's originality and contribution.

Keywords Industry 4.0, Manufacturing management, Training, Human resource management, Knowledge transfer

Paper type Research paper

Funding: The study was funded by Conselho Nacional de Desenvolvimento Cientıfico e Tecnologico (CNPq) [Award number: 307536/2018-1 and 140998/2020-9].

Kybernetes

0368-492X
DOI 10.1108/K-03-2022-0365

K

Introduction

The term "Industry 4.0" was firstly mentioned in 2011 at a press conference at the Hannover Fair, considering a vision of the future manufacturing system. This term has international recognition with a broad dimension so much that it has been considered an industrial revolution (fourth industrial revolution) due to its impacts on the social, political, and economic spheres (Collan and Michelsen, 2020). Specific to the manufacturing industry, "Industry 4.0" refers to a new technological platform beginning in the relations with suppliers and arriving up to the delivery of the product to the customer (Ghobakhloo and Azar, 2018; Gilchrist, 2016; Wilkesmann and Wilkesmann, 2018). According to Tortorella and Fettermann (2018), this new scenario offers several advantages: increased productivity, better efficiency of available resources, and reduction in waste generation.

In this context, a holistic view based on three main factors (technology, organisation, and human) has been adopted (Dregger *et al.*, 2016; Ittermann *et al.*, 2016; Reuter *et al.*, 2017; Sony and Naik, 2020). According to Koleva and Andreev (2018), the human factor is one of the pillars of Industry 4.0 and production managers are more demanded in their ability to solve complex problems, creativity, and critical thinking (Brougham and Haar, 2018; Frey and Osborne, 2017).

The organisations must deal with the continuous qualification of the human worker as a priority action for the implementation and development of Industry 4.0 (Kagermann *et al.*, 2013; Koleva and Andreev, 2018; Perini *et al.*, 2017; Popkova and Zmiyak, 2019; Yang *et al.*, 2018). Managers need to spread a clear vision of the organisation's strategy and encourage their teams to act towards innovation. This requires prepared leadership capable of guiding and motivating employees towards a common goal (Helming *et al.*, 2019; Sony and Naik, 2020). To implement this scenario, training employees and managers at all hierarchical levels becomes increasingly important (Perini *et al.*, 2017). According to Kagermann *et al.* (2013), Popkova and Zmiyak (2019) and Rocha *et al.* (2018), training and continuous professional development are considered priority actions for the implementation and development of Industry 4.0.

Collan and Michelsen (2020) reinforce this scenario, presenting that one of the main barriers to the development of technology skills is the low level of employee participation in training. Cazeri *et al.* (2022) performed a systematic literature review to identify and classify the main features explored by current research encompassing training for Industry 4.0 and found a gap concerning studies targeting managers who deal with Industry 4.0. Additionally, Cazeri *et al.* (2022) mention studies of CNI (Confederação Nacional das Indústrias, 2018), FIESP (FIESP, 2018), and Firmino *et al.* (2020), which show that in Brazil there are many entrepreneurs and managers unfamiliar with Industry 4.0 concepts and it generates a significant knowledge gap in manufacturing companies segment.

Considering the context previously described, one of the purposes of this study is to identify the main challenges in performing training for managers of manufacturing sector who are unfamiliar with Industry 4.0 concepts and aspire a broad view on the subject. The Delphi method was used to achieve this goal because it combines the different opinions of a group of experts to achieve a consensus (Donohoe and Needham, 2009; Gbededo and Liyanage, 2020). In addition, this study aims to validate practices to be adopted in the training mentioned above, and for this purpose, the Fuzzy Delphi method was applied. Fuzzy Delphi can be seen at Kuo and Chen (2008) and Stefano *et al.* (2014).

Besides this introduction, this paper has additional four sections. Theoretical background regarding suitable practices may be used in training. The methodological procedures used to provide details to allow the replication of the study. The results and associated debates are presented in the next section. The last section shows the main conclusions, followed by the list of references.

Theoretical background

According to Collan and Michelsen (2020), the historical context presents manufacturing systems as physical artefacts containing immaterial constituent parts–they use natural resources and social, political, and cultural resources, such as knowledge and legislation, regulation, and ideology. For Industry 4.0, manufacturing systems are complex large technological systems managed by highly trained professionals.

Kagermann *et al.* (2013, p. 5) consider the aims of Industry 4.0:

> It will address and solve some of the challenges facing the world today such as resource and energy efficiency, urban production, and demographic change. It enables continuous resource productivity and efficiency gains to be delivered across the entire value network. It allows work to be organised in a way that takes demographic change and social factors into account. Smart assistance systems release workers from having to perform routine tasks, enabling them to focus on creative, value-added activities. In view of the impending shortage of skilled workers, this will allow older workers to extend their working lives and remain productive for longer. Flexible work organisation will enable workers to combine their work, private lives, and continuing professional development more effectively, promoting a better work-life balance

This scenario implies that human skills are important for Industry 4.0 and skilled workers are needed to supervise production and manage complicated issues (Collan and Michelsen, 2020). Additionally, Ardito *et al.* (2019), Dregger *et al.* (2016), Ghobakhloo (2018), Ghobakhloo (2020), Hermann *et al.* (2016), Oztemel and Gursev (2020) and Reuter *et al.* (2017) reinforce the importance of the human factor in Industry 4.0 considering that Industry 4.0 combines production agents (machines, robots, and operators) through a network of connections and information management based on three main factors: technology, organisation, and human factors.

Taking into account the human factor, Jain *et al.* (2021) consider the most significant weakness to the implementation of Industry 4.0 is related to the need for training, and the most significant threat is related to the resistance of workers to adopt new technologies. Bakhtari *et al.* (2021) present the lack of leadership from the management, lack of skills for training and education programs, and lack of qualified workforce as the main challenges in implementing Industry 4.0. Thus, training and continuous professional development deserve special attention and importance for Industry 4.0 (Kaya *et al.*, 2020; Schallock *et al.*, 2018).

According to Helming *et al.* (2019), Moeuf *et al.* (2018) and Sony and Naik (2020), the need for training is particularly important for managers because they are required to be capable of guiding the change of an organisation to Industry 4.0 by handing over the correct vision, leading and motivating employees towards a common goal, creating the proper culture, and making the proper alliances. Additionally, managers should enhance staff training to enable members to adopt and implement workplace technologies related to Industry 4.0 (Collan and Michelsen, 2020).

Salas *et al.* (2012, p. 74) state that "*there is a science of training that shows that there is a right way and a wrong way to design, deliver, and implement a training program*". According to Bell *et al.* (2017) and Noe *et al.* (2014), the science of training has expanded to emphasise individual capabilities and team effectiveness for organisations to obtain competitive advantages. Also, the science of training has progressed in the last decades, adopting models, designs, technologies and concepts related to the organisational context (Bisbey *et al.*, 2019; Salas and Cannon-bowers, 2001).

There is a consensus amongst researchers that training should consider practices in three main phases: "practices applied before training", "practices applied during training", and "practices applied after training" (Goldstein, 1993; Kodwani, 2017; Massenberg *et al.*, 2015, 2017; Salas *et al.*, 2012, 2015; Salas and Cannon-bowers, 2001; Yang *et al.*, 2018). Regarding the first phase, the trainer must know organisational conditions in which the training will be offered and the main characteristics of participants. This is essential to prepare good content.

For Bell *et al.* (2017), the learning and the transfer of knowledge are closely linked to organisational conditions and the design of the training need to consider this.

Regarding the second phase, the interest of professionals in training is one of the main characteristics that strongly influences the training results (Salas *et al.*, 2012). Therefore, it is essential to present to them the organisation's training policy, training needs and how they align with the organisation's strategic objectives. In addition, trainers need to adopt the appropriate pedagogical approach and learning methodology, besides the use of techniques to motivate participants (Larson, 2020; Salas *et al.*, 2012, 2015; Sanna Jr. and Goshorn, 2017; Taylor and Bisson, 2019; Tews and Noe, 2019; Yang *et al.*, 2018).

Finally, in the last phase, it is essential to evaluate the knowledge acquired by the participants. It is important to use accurate affective, cognitive, and behavioural indicators to measure learning outcomes. Four levels of outcomes can be measured: reactions (did participants enjoy the training?), learning (principles, facts, or skills learnt by participants), behaviour (changes in behaviour at work), and results (tangible results of the training, such as increasing profitability or reducing the number of errors) (Kirkpatrick and Kirkpatrick, 2006; Powell and Yalcin, 2010; Salas *et al.*, 2012, 2015; Yang *et al.*, 2018).

Figure 1 presents an analytical framework organising the key topics related to the training for managers unfamiliar with Industry 4.0 theme that guided this study's research questions and the study's subsequent phases presented in the following sections.

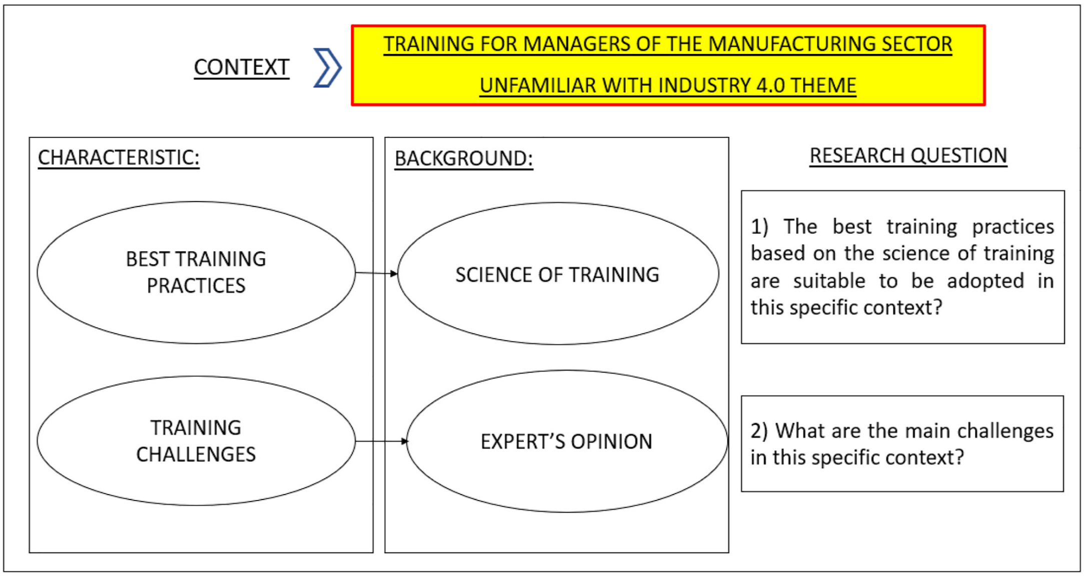
Methodological procedure

This research was carried out through three stages, according to Figure 2.

In stage 1, the preferred reporting items for systematic review and meta-analysis (PRISMA) methodology (Moher *et al.*, 2009) oriented this study to ensure a replicable and robust systematic literature review once it is widely used to guide the development of systematic literature reviews in various research fields. As a result, it was possible to structure Table 1 with the best training practices based on the science of training. This Table was considered a starting point for applying the Fuzzy Delphi method.

In stage 2, the Delphi method and the Fuzzy Delphi method were structured and applied.

Delphi is a method that combines the specialised opinions of a group of participants to provide a consensus on a problem with several points of view (Donohoe and Needham, 2009;



Source(s): The authors

Figure 1.
Analytical framework

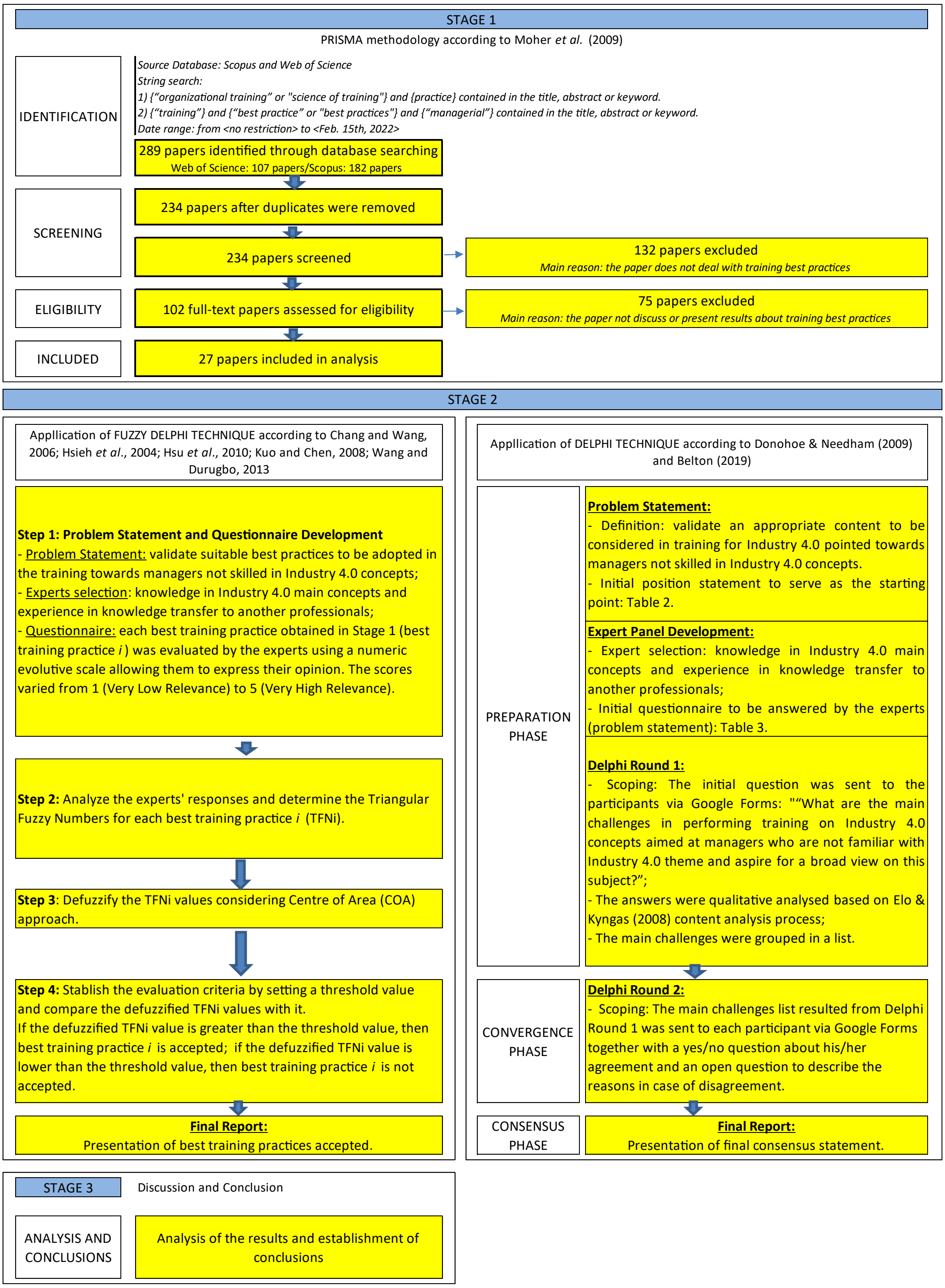


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Figure 2.
Methodological framework

Gbededo and Liyanage, 2020). According to Powell (2003), the Delphi method is helpful for situations in which individual judgements must be used and combined to complete the state of knowledge concerning a particular topic. The mentioned method help researcher to structure and organise the communication of a group of participants. This application of the Delphi method identifies the main challenges in performing training on Industry 4.0 concepts

Table 1.
Best training practices based on the science of training

Item	Practices to be adopted before training (Plan phase)
1	Conduct a prior debate with the organisation board to identify possible obstacles or barriers that may affect training effectiveness and conduct an organisational analysis to enable the correct insertion of training in the organisation's objectives. (Bell *et al.*, 2017; Kodwani, 2017; Salas *et al.*, 2012, 2015)
2	Collect information about the professionals in training and promote appropriate learning approaches: performance-based learning or knowledge-based learning. (Bell *et al.*, 2017; Cheng *et al.*, 2019; Salas *et al.*, 2012, 2015; Yang *et al.*, 2018)
3	Collect information about the current competencies of the professionals in training and compare them with the competencies that must be developed. (Hecklau *et al.*, 2016; Li *et al.*, 2019; Salas *et al.*, 2012, 2015; Yang *et al.*, 2018)
4	Analyse the training schedule and duration. Search for dates in which professionals in training may have more dedication to training and carry out several training sessions rather than a single day of the event. (Cheng *et al.*, 2019; Kodwani, 2017; Piñol, Porta *et al.*, 2017; Salas *et al.*, 2012, 2015; Taylor and Bisson, 2019; Yang *et al.*, 2018)
Item	*Practices to be adopted during training (Do Phase)*
5	Present the organisation's training policy, attendance rules, training needs, and how the training is aligned with the organisation's strategic objectives. (Salas *et al.*, 2012, 2015; Sanna and Goshorn, 2017)
6	Structure training content considering pedagogical approaches. (Bell and Kozlowski, 2008; Salas and Cannon-bowers, 2001; Taylor and Bisson, 2019; Tian *et al.*, 2015)
7	Utilise techniques that motivate and maintain professionals in training attention: insert audio or video media in an adequate moment; insert fun in the content to be learnt and encourage self-regulatory activities (Bell and Kozlowski, 2008; Rangel *et al.*, 2015; Read and Kleiner, 1996; Salas *et al.*, 2015; Tews and Noe, 2019; Yang *et al.*, 2018)
8	Utilise active learning methodology, such as the Project or Problem-Based Learning (PBL), to apply learning in work environment situations. Encourage teamwork, situations with significant chances of errors, and debates to think "out of the box". (Bell *et al.*, 2017; Bell and Kozlowski, 2008; Piñol *et al.*, 2017; Read and Kleiner, 1996; Salas *et al.*, 2012, 2015; Stankunas *et al.*, 2016; Werth, 2011; Yang *et al.*, 2018; Yeardley, 2017)
9	Utilise technologies integrated with active learning methodology such as "virtual simulations", "gamification", blended learning, Augmented Reality (AR), Virtual Reality (VR), and others. (Armstrong and Landers, 2018; Bell *et al.*, 2017; Hamari and Sarsa, 2014; Landers and Armstrong, 2017; Larson, 2020; Read and Kleiner, 1996; Salas *et al.*, 2012, 2015; Strubelt *et al.*, 2019)
Item	*Practices to be adopted after training (Check Phase)*
10	Specify the purpose of evaluating training clearly and link all subsequent decisions about measuring with the specified purpose. Use effective, cognitive, and behavioural indicators to measure learning outcomes. (Bell *et al.*, 2017; Kodwani, 2017; Salas *et al.*, 2012, 2015; Yang *et al.*, 2018)
11	Measure outcomes in four levels: reactions (did participants enjoy the training?), learning (principles, facts, or skills learnt by participants), behaviour (changes in behaviour at work), and results (tangible results of the training, such as increasing profitability or reducing the number of errors) (Kirkpatrick and Kirkpatrick, 2006; Powell and Yalcin, 2010; Salas *et al.*, 2012, 2015; Yang *et al.*, 2018)
12	Issue training certificate only after professional in training approval. (Yang *et al.*, 2018)

Source(s): The authors

to managers in the manufacturing sector who are unfamiliar with the theme and aspire for a broad view on the subject.

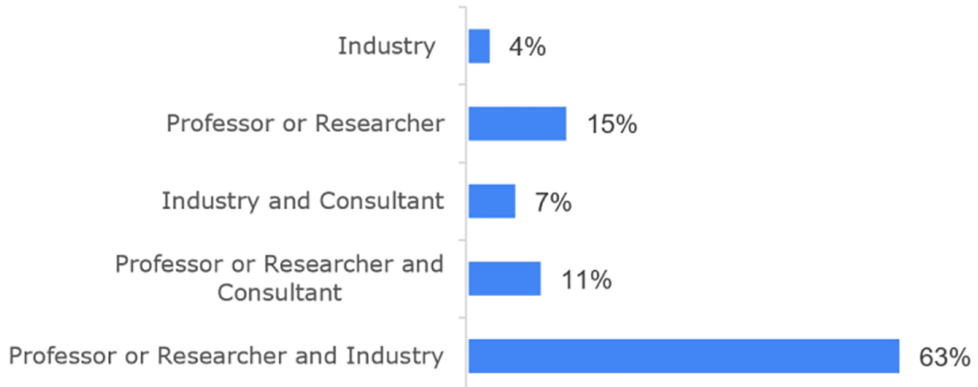
Hanafin *et al.* (2007) and Linstone (1985), cited by Donohoe and Needham (2009), argue that the Delphi method stands out due to its flexibility. The method can be used in studies when presential meetings are not possible due to different aspects, or there are temporal conflicts in participants' agendas. Thus, the opportunity to consult experts is not lost, even if they are in different regions and cannot participate simultaneously, for example. Currently, the Delphi method is applied in different research areas (Donohoe and Needham, 2009; Powell, 2003).

According to Geist (2010), Hasson *et al.* (2000) and de Jesus *et al.* (2019), a critical success factor for the Delphi method is the expert selection and it is presented in the "preparation phase" of stage 2 in Figure 2. In this research, the experts' selection considered knowledge of Industry 4.0 main concepts, experience related to Industry 4.0 pillars or technological innovations, and their experience in transferring this knowledge to other professionals. The search for experts who meet these requirements was based on professional networks, academic platforms, industry 4.0 recognised networks, and websites of companies recognised by Industry 4.0 projects.

Fifty-three experts who met the initial research criteria (knowledge of Industry 4.0 theme and experience in transferring knowledge about Industry 4.0) were invited to participate in this study and twenty-seven accepted the invitation. As presented in Figures 3 and 4, most of the participants hold a PhD and work as professors or researchers with experience working in the industry.

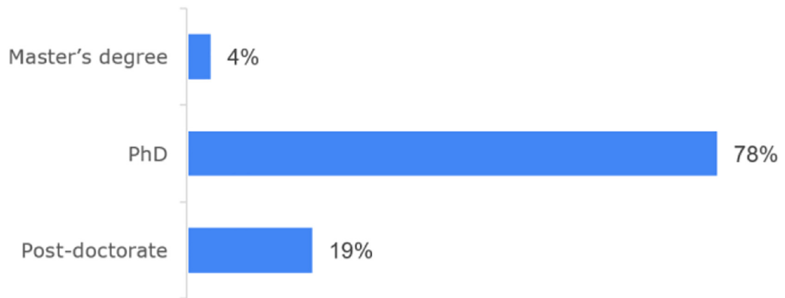
Further, in Delphi round 1, a questionnaire was sent to all participants and the Delphi method carried out in this study began with the following question: "*What are the main challenges in performing training on Industry 4.0 concepts aimed at managers who are not familiar with Industry 4.0 theme and aspire for a broad view on this subject?*" As can be noted, it is a fully open question in which each participant could freely express his/her own opinion. It is essential to highlight that Ethics Research Committee approved the study and data collection started only after this approval. After receiving the responses, the moderator of the process starts their analysis and synthesis. To analyse the data collected in each round, the content analysis was applied, according to Elo and Kyngäs (2008) guidelines.

In Delphi round 2, the result of the analysis is sent to each participant and he/she can see the statements made by others participants anonymously and reflect on them. In the face of this new information, each participant can maintain, complement or change his/her viewpoint. The new questions in this round are (1) "*Do you agree that the list presented summarises the main challenges for carrying out training on I4.0 aimed at managers who are unfamiliar with the subject and wish to obtain a broad view of the subject?*" (Yes/No answer) and (2) "*If you do not agree, justify*" (open question). This iterative process allows new themes and



Source(s): The authors

Figure 3. Participant's classification according to professional activity



Source(s): The authors

Figure 4. Participant's classification according to academic qualification

ideas to emerge in each round and the rounds occur until a consensus is reached (Brown, 2007; Linstone and Turoff, 1975).

It is important to emphasise that consensus does not mean unanimity; a consensus is reached when most participants, and not all of them, have the same opinion in the final round. A typical evaluation in Delphi studies applies a percentage level for participants' agreement, which varies from 50% to 80% of participants' agreement for consensus to be reached (Powell, 2003). Chang *et al.* (2010) and Belton *et al.* (2019) consider that in a broad research environment, with the involvement of different areas of knowledge, the minimum percentage level of agreement amongst participants must be 75% for consensus to be obtained. Gbededo and Liyanage (2020) consider that the minimum percentage level of agreement amongst participants must be 80% for consensus to be obtained.

Simultaneously, the Fuzzy Delphi method was applied for the validation of best training practices. This method is appropriate because there is a starting point list of twelve best training practices based on a systematic literature review and Fuzzy Delphi allows: (1) creates a better criterion selection effect; (2) gives a different degree of adherence to each possible consensus; (3) respects the original opinions of all the experts; (4) prevents useful information from being lost (Kuo and Chen, 2008; Stefano *et al.*, 2014). The Fuzzy Delphi method is the combination of Fuzzy Set Theory and the Delphi method initially proposed by Murray *et al.* (1985) and its application occurs via four steps as detailed in the sequence. These steps are based on different authors (Chang and Wang, 2006; Hsieh *et al.*, 2004; Hsu *et al.*, 2010; Kuo and Chen, 2008; Wang and Durugbo, 2013), and it was also used by Stefano *et al.* (2014).

Step 1: Organise an appropriate group of experts and elaborate a questionnaire using a numeric evolutive scale to allow the participants to express their opinions regarding each best training practice presented in Table 1 (best training practice i).

These are the same fifty-three participants presented in the Delphi method.

The participants should give only one score for each best training practice presented in Table 1 (best training practice i) considering the following scale: 1 (Very Low Relevance), 2 (Low Relevance), 3 (Medium Relevance), 4 (High Relevance), and 5 (Very High Relevance). Each score presented by the participant was denoted as R_{ij}, where the index of practice i is rated by respondent j.

Step 2: Analyse the experts' responses and determine the Triangular Fuzzy Numbers (TFNs) for each best training practice i. The TFN values are composed of three elements (L_i; M_i; U_i) - see (Kuo and Chen, 2008); where:

L_i: indicates the minimum of all the experts' rating value for the best training practice i;

M_i: is the geometric mean of all the experts' rating value for the training practice i, determined as follow: $M_i = \left(\prod_{j=1}^{k} R_{ij}\right)^{1/k}$;

U_i: indicates the maximum of all the experts' rating value for the best training practice i.

So, the index $TFN_i = (L_i; M_i; U_i)$ is established for each best training practice i.

Step 3: Once the TFN_i is determined, the Centre of Area (COA) approach is used to defuzzify the TFN_i values, as applied in Hsieh *et al.* (2004), Wang and Durugbo (2013). The value COA_i, for each best training practice i, is calculated as follows:

$$COA_i = [(U_i - L_i) + (M_i - L_i)]/3 + L_i$$

Step 4: The evaluation criteria are established by setting the threshold value α as follows (Stefano *et al.*, 2014):

$$\alpha = \frac{(U + L)}{2}$$

where: U: indicates the maximum possible rating value; L: indicates the minimum possible rating value.

Principle of screening:

- if $COA_i \geq \alpha$; then best training practice i is *accepted* and
- if $COA_i \leq \alpha$; then best training practice i is *not accepted*.

After the presentation of the final report, stage 3 brings out the analysis of the results and the establishment of conclusions.

Results and analysis

Delphi method results and debates

In the first round, the individual answers received by each of the twenty-seven experts were clustered and synthesised by the moderator. Table 2 presents the result of considering eleven main challenges associated with Industry 4.0 concepts training.

The eleven main challenges from the first round were the basis for the second round. Table 2 was presented to all participants in the second round. In this way, each participant could check the synthesis performed by the moderator and know the point of view of other participants (without knowing their identity due to anonymity). Considering the new statements, participants could complement or change their answers if it was necessary.

Table 3 presents the percentages of concordances for each challenge presented in Table 2. It is important to mention that seven respondents dropped out on this round, and the Delphi method was finalised with twenty respondents. The literature mentions that dropouts are common throughout rounds and the quantity of twenty participants is sufficient for the Delphi method application (Belton *et al.*, 2019; Geist, 2010; Hasson *et al.*, 2000; de Jesus *et al.*, 2019; Rowe and Wright, 2001).

As it can be noted in Table 3, each challenge presented in Table 2 reached a percentual of agreement higher than 80.0%. Based on Belton *et al.* (2019), Chang *et al.* (2010), Gbededo and Liyanage (2020) and Powell (2003), it is possible to affirm that each challenge presented in Table 2 is relevant for managerial training in Industry 4.0.

It has been observed that challenges 1 and 8 of Table 2 are related to "necessary knowledge" in different areas for professionals in training on the fundamentals and principles of Industry 4.0. There are two situations: when specific professionals in training do not have the minimum necessary knowledge in a specific area and when the group that will receive the training present a significant heterogeneity. It is noteworthy that according to studies performed by CNI (2018), FIESP (2018), and Firmino *et al.* (2020), cited by Cazeri *et al.* (2022), there are still a significant number of managers with no knowledge regarding the Industry 4.0 concepts and principles in Brazil.

Challenges 2, 3, and 10 of Table 2 can be understood as "breaking paradigms". These challenges aimed to show that Industry 4.0 principles can be applied in all types of companies and are not associated only with technology adoption. It is necessary to deal with cultural changes, implement consolidated strategies and think in a long-term oriented view, as Sony and Naik (2020) recommended in their critical factors.

In turn, challenges 4, 9, and 11 of Table 2 are related to how to conduct the training. These challenges are related to the difficulties of not being repetitive, the need to develop dynamics to improve participants learning, and how to assess participants understanding throughout the process. The issue of being repetitive becomes more complex the more significant the heterogeneity of the group since the trainer often needs to return to the presentation of some

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Item number	"What are the main *challenges* in performing training on Industry 4.0 concepts aimed at managers who are unfamiliar with Industry 4.0 theme and aspire for a broad view on this subject?"
1	Overcome barriers related to the minimum necessary level of knowledge about mathematics, statistics, programming, and automation, even though it is focussed on management level professionals
2	Break up the perception that Industry 4.0 concepts and principles are available only for renowned companies and far away from Brazilian companies in general
3	Become evident to professionals in training that Industry 4.0 adoption and implementation is not characterised as a fast and standard solution. It requires adopting a broad concept not only linked to the automation of production or provision of services. Managers need to understand the business culture, the company's strategy, and other factors that affect the organisation's reality. Indeed, Industry 4.0 adoption and implementation is a great challenge
4	Structure the theoretical part of the training to be offered on concepts, principles, and technologies without being repetitive
5	Make the professionals in training able to identify the applicability of Industry 4.0 in their companies' production processes. Present examples and real case studies based on contexts close to or even already experienced by the professionals in their company so that the learning can be enhanced
6	Ensure professionals in training can identify the potential gains arising from the applicability of Industry 4.0 concepts in their companies' production processes
7	Become the professionals in training able to reflect on the business model of their companies and also on the business model practised by their competitors in light of the concepts presented
8	Adapt how concepts and principles should be taught based on professionals in training's heterogeneity, outdatedness, and difficulty in acquiring more technical and advanced knowledge
9	Develop specific dynamics to allow the practice of Industry 4.0 concepts and principles by the professionals in training
10	Break up the preconceived idea of professionals in training that Industry 4.0 are only based on complex technologies and make clear the need for a model that fully integrates the complex technology implementation aligned with the business strategies of the company
11	Measure the professionals in training understanding of Industry 4.0 concepts and principles throughout the training

Source(s): The authors

Table 2.
Delphi method first-round results

Item number in Table 2	Quantity of agreement	Percentual of agreement (%)
1	17	85.0%
2	19	95.0%
3	19	95.0%
4	19	95.0%
5	20	100.0%
6	20	100.0%
7	20	100.0%
8	20	100.0%
9	20	100.0%
10	20	100.0%
11	19	95.0%

Source(s): The authors

Table 3.
Percentage of the agreement for each challenge individually

concepts already explained to solve existing doubts. As previously described, on the Industry 4.0 theme, there is significant heterogeneity in the knowledge of the participating professionals in the Brazilian context. Regarding the dynamics to improve professionals in training learning, they are excellent for improving the understanding of theoretical concepts in training processes (Bell *et al.*, 2017; Kodwani, 2017; Salas *et al.*, 2012, 2015); however, training focussed on Industry 4.0 theme, they are not always fully available when compared to other management themes. In addition, their idealisation is not always immediate.

Regarding the assessment of participants' understanding throughout the training process, this is essential to achieve the goals, and it is complex in the context of training on industry 4.0 concepts and principles. Important training practices are presented in Table 1 of Section 2, and this study analysed them in the context of Industry 4.0 (see item 4.3).

Finally, challenges 5, 6, and 7 of Table 2 are related to the expected results of the training; that is, we expected that the professionals who participated in the training know how to identify the applicability of the concepts and principles of Industry 4.0 in the production processes, as well the possible gains due to applicability. In addition, we also expected that they know to reflect on the impacts on the business model of their companies and competitors. Therefore, these are considerable challenges.

Figure 5 summarises, after grouping, the main challenges for conducting Industry 4.0 training aimed at managers who are unfamiliar with them and aspire for a broad view on this subject.

Fuzzy Delphi method results and debates

Regarding the results of the Fuzzy Delphi method, initially, we present a synthesis of the values that allow structuring Triangular Fuzzy Numbers (TFN_i) in Table 4.

Source(s): The authors

Figure 5. Main challenges to conducting Industry 4.0 training for managers unfamiliar with the theme

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Table 4.
TFN_i values for each best training practice

Training practice item (*)	Minimum of all experts' rating value (L_i)	The geometric mean of all the experts' rating values (M_i)	Maximum of all experts' rating value (U_i)	TFN_i values
1	2	4.24	5	(2; 4.24; 5)
2	3	4.02	5	(3; 4.02; 5)
3	2	4.29	5	(2; 4.29; 5)
4	2	3.56	5	(2; 3.56; 5)
5	1	3.24	5	(1; 3.24; 5)
6	2	4.01	5	(2; 4.01; 5)
7	2	3.97	5	(2; 3.97; 5)
8	2	4.55	5	(2; 4.55; 5)
9	2	4.17	5	(2; 4.17; 5)
10	2	3.67	5	(2; 3.67; 5)
11	2	4.08	5	(2; 4.08; 5)
12	1	2.95	5	(1; 2.95; 5)

Note(s): (*) The correspondence between the item number and the training practice description is according to Table 1
Source(s): The authors

In the sequence, the COA approach was used to defuzzify the TFN_i. The values obtained were compared with the threshold value (α). Table 5 presents the comparison amongst COA_i values and threshold values (α).

As shown in Table 5, only practice 12 had the COA_i value less than the threshold (α). The eleven remaining practices had COA_i values greater than the threshold values (α). So, based on the methodology used, it is possible to infer that practices 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 are accepted and can be considered in Industry 4.0 training. On the other hand, practice 12 is not accepted as critical practice in Industry 4.0 training.

As mentioned by Kagermann *et al.* (2013), Koleva and Andreev (2018), Perini *et al.* (2017), Popkova and Zmiyak (2019) and Yang *et al.* (2018), training in Industry 4.0 is an essential aspect of organisations and should be considered as a priority action; in this sense, the eleven practices validated here can be used by professionals to offer better training and reach better results in implementation programs.

Table 5.
Center of area, threshold, and screening of the values

Training practice item	Center of area values (COA_i)	Threshold values (α)	Comparison between center of area values (COA_i) and threshold values (α)	Screening
1	3.75	3.0	$G_i > \alpha$	Accepted
2	4.01	3.0	$G_i > \alpha$	Accepted
3	3.76	3.0	$G_i > \alpha$	Accepted
4	3.52	3.0	$G_i > \alpha$	Accepted
5	3.08	3.0	$G_i > \alpha$	Accepted
6	3.67	3.0	$G_i > \alpha$	Accepted
7	3.66	3.0	$G_i > \alpha$	Accepted
8	3.85	3.0	$G_i > \alpha$	Accepted
9	3.72	3.0	$G_i > \alpha$	Accepted
10	3.56	3.0	$G_i > \alpha$	Accepted
11	3.69	3.0	$G_i > \alpha$	Accepted
12	2.98	3.0	$G_i < \alpha$	*Not accepted*

Source(s): The authors

In summary, best training practices to be adopted before training should consider a prior debate with the organisation board, collection of information about the professionals in training, and planning training agenda (date, duration of each session, number of sessions, etc.). The best training practices to be adopted during training should consider the presentation of training needs and their alignment with the organisation's strategic objectives, the appliance of an adequate pedagogical approach, the use of motivation techniques, the use of active learning methodology, and the use of technology integrated with active learning methodology. Finally, the best training practices to be adopted after training should consider evaluation practices as follows: Specify the purpose of evaluating training clearly and link all subsequent decisions about measuring with the specified purpose, and measurement of outcomes in four levels: reactions (did participants enjoy the training?), learning (principles, facts, or skills learnt by participants), behaviour (changes in behaviour at work), and results (tangible results of the training, such as increasing profitability or reducing the number of errors) (Bell *et al.*, 2017; Cheng *et al.*, 2019; Kirkpatrick and Kirkpatrick, 2006; Kodwani, 2017; Larson, 2020; Piñol *et al.*, 2017; Powell and Yalcin, 2010; Salas *et al.*, 2012, 2015; Sanna and Goshorn, 2017; Taylor and Bisson, 2019; Tews and Noe, 2019; Yang *et al.*, 2018).

Implications for managerial training

The main challenges and best practices to be adopted in training introduce a way to transform the current scenario of the managerial class, pushing it towards Industry 4.0. Based on the main challenges presented, the current perception of managers unfamiliar with the Industry 4.0 theme is that it is something accessible only to renowned companies and far from their current reality. This paradigm needs to be broken to enable, at an initial stage, the interest of managers in Industry 4.0 and, consequently, enable these managers to lead the development of Industry 4.0 in their organisations.

Training also must contain practical examples of Industry 4.0 application and activities concerning the identification of Industry 4.0 applicability in their companies' production processes. The managerial class needs to reflect and identify potential gains from the applicability of Industry 4.0 concepts and promote its interest in implementing and developing Industry 4.0 concepts.

Subsequently, it is important to break the paradigm that the adoption of Industry 4.0 is exclusively related to the automation of production and implementation of related technologies, and it is carried out in a standardised and fast way. The managerial class needs to understand the business culture, the company's strategy and other related factors that affect the adoption and implementation of Industry 4.0. This main challenge is connected with the best practice to be adopted before training related to a prior debate with the organisation board to identify possible obstacles or barriers that may affect training effectiveness. In this prior debate, the trainers must collect information regarding the company's strategy to transmit it to the managers and enable the correct insertion of training in the organisation.

It is also important to mention the main challenge related to developing specific dynamics to allow the practice of Industry 4.0 concepts and principles is connected with utilising active learning methodology (best practice to be adopted during the training – item 8 of Table 1), such as the Project or Problem-Based Learning (PBL) and applied learning in work environment situations. In addition, the main challenge related to measuring the managers training understanding of Industry 4.0 concepts and principles is related to best practices to be adopted after the training (item 10 and item 11 of Table 1). At last, the main challenge related to the structuration of the theoretical part of the training without being repetitive is connected with using technologies integrated with active learning methodology such as "virtual simulations", "gamification", blended learning, Augmented Reality (AR), Virtual Reality (VR), and others and the appliance of techniques that motivate and maintain professionals in training attention (best practice to be adopted during the training – item 9 and item 7, respectively).

Conclusions

This study aims to identify the main challenges in training on Industry 4.0 concepts for managers unfamiliar with this theme and validate practices that reduce managerial knowledge differences. Based on the results, it is possible to affirm that the objectives were achieved.

The results present eleven main challenges identified by applying the Delphi method and eleven practices validated through the Fuzzy Delphi method. The eleven challenges were grouped into four clusters: challenges associated with the necessary knowledge; challenges of breaking paradigm; challenges associated with training characteristics; and challenges associated with expected results. The eleven training practices were validated, including actions to be adopted before, during, and after the training process. Also, it can be noted a connection between the main challenges validated through the Delphi method and the best training practices validated through the Fuzzy Delphi method; consequently, the best training practices can help overcome the main challenges related to training in Industry 4.0.

The limitation of this study is related to the opinion and comments of its participants. Another group of participants may lead to different results, although the participants' characterisation confers credibility to the findings, so, as a future research proposal, this research can be replicated by considering other participants with similar professional activities and academic qualifications.

These main challenges and training practices can be considered for practical application as a future research proposal, thus making it possible to assess their effectiveness in transmitting knowledge. Specific to the main challenges, future research can consider applying weighting methods (such as Best Worst Method (BWM), Analytical Hierarchy Process (AHP), or related ones) to rank the main challenges presented in this research. Additionally, researchers or trainers can consider the presented results for improving their current training programs. Overall, we expect this study to reduce the managerial knowledge gap concerning the Industry 4.0 subject and, consequently, contribute to the development and implementation of Industry 4.0 concepts.

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Routledge
Taylor & Francis Group

Technology Analysis & Strategic Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ctas20

Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?

Gustavo Tietz Cazeri, Luis A. Santa-Eulalia, Milena Pavan Serafim, Izabela Simon Rampasso & Rosley Anholon

To cite this article: Gustavo Tietz Cazeri, Luis A. Santa-Eulalia, Milena Pavan Serafim, Izabela Simon Rampasso & Rosley Anholon (2022): Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?, Technology Analysis & Strategic Management, DOI: 10.1080/09537325.2022.2131513

To link to this article: https://doi.org/10.1080/09537325.2022.2131513

Published online: 11 Oct 2022.

TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT
https://doi.org/10.1080/09537325.2022.2131513

Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?

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ABSTRACT

This study aims to validate adequate content for Industry 4.0 training recommended to managers unfamiliar with this theme and intends to get a holistic view. A Delphi Method was conducted with experts in Industry 4.0 and training. These experts evaluated an initial training content structure segmented into seven modules based on academic literature. The consensus was reached in two rounds with the participation of twenty-seven (27) experts in the first round and twenty (20) experts in the second round. The results were discussed considering literature statements. The initial training content structure was reordered and an additional module was appended. The validated training content structure considers a total of eight modules ordered as follows: Business Management Models Impact; Product Personalisation and Smart Products; Smart Factory and Integration; Modularity and Service Orientation; Decentralisation and Interoperability; Virtualisation and Real-Time Capability; Corporate Social Responsibility (CSR) and Sustainability Impact; and Industry 4.0 Implementation. The results presented here are helpful for academics, consultants, and professionals who need to design courses and training about Industry 4.0 theme. It is essential to mention that no similar papers were found in scientific databases, reinforcing the originality and the contribution of this research.

ARTICLE HISTORY
Received 2 September 2021
Revised 18 August 2022
Accepted 26 September 2022

KEYWORDS
Industry 4.0; training; Delphi method

1. Introduction

The term Industry 4.0 was coined by the German association 'Industrie 4.0' in 2011 (Ardito et al. 2019) and represents the fourth industrial revolution based on emerging technology breakthroughs in fields such as robotics, the Internet of Things, artificial intelligence, 3-D printing, energy storage, materials science, among others along with the communication between computers, machines and intelligent materials with each other and with humans as well. (Elibal and Özceylan 2020; Ghobakhloo and Azar 2018; Gilchrist 2016; Rocha, Mamédio, and Quandt 2019; Wilkesmann and Wilkesmann 2018).

Currently, these concepts extrapolate the industrial environment and are applied to aim the improvement of society as a whole in services applied to citizens, among other various fields. For example, the ISO 37122:2020 standard deals with the application of technologies aimed at the needs of cities to ensure the well-being of their residents (de Souza Lobato et al. 2021; Maja, Meyer, and Von Solms 2020).

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According to Schwab (2016), this revolution 'will change the way we live, work, and relate to one another'. Specific to organisations, this fourth industrial revolution takes place across the entire value chain, initiating relations with suppliers and arriving up to the delivery of the product to the customer (Ardito et al. 2019; Wilkesmann and Wilkesmann 2018). According to Ghobakhloo (2018), the Industry 4.0 phenomenon is based on twelve fundamental design principles: 'Service Orientation, Smart Product, Smart Factory, Interoperability, Modularity, Decentralization, Virtualization, Real-Time Capability, Vertical Integration, Horizontal Integration, Product Personalisation, and Corporate Social Responsibility'.

Based on this scenario, a holistic view supported by the technological factor, organisational factor and the human factor is gaining prominence and the term 'socio-technical system' and 'social manufacturing' is being established in current publications (Dregger et al. 2016; Ittermann, Niehaus, and Hirsch- 2016; Reuter et al. 2017). Sony and Naik (2019) consider that employees and change management are critical factors of success for Industry 4.0 implementation. Change management requires CEO-led changes and the management becomes responsible for conducting the changes by creating the proper culture, giving the correct vision, motivating and encouraging employees towards a common goal, and establishing the necessary agreements in the organisation. Consultants are also required to act as agents of change due to the knowledge base (Helming et al. 2019; Sony and Naik 2019).

As a consequence, training in Industry 4.0 is a strategic organisational action and it is an essential aspect that organisations must deal with (Kagermann, Wahlster, and Helbig 2013; Koleva and Andreev 2018; Perini et al. 2017; Popkova and Zmiyak 2019; Yang et al. 2018). According to Törngren et al. (2015), well-trained professionals will be essential for the implementation and development of Industry 4.0. Despite its importance, it is still a gap for countries (Contieri, Anholon, and De Santa-Eulalia 2022). For Gorecky, Khamis, and Mura (2017) and Rocha et al. (2018), continuous qualification of the human worker and the introduction of new approaches for delivering knowledge and transferring skills is mandatory in Industry 4.0 context. Kagermann, Wahlster, and Helbig (2013) and Popkova and Zmiyak (2019) reinforce this context, considering training and continuous professional development as priority actions for implementing and developing Industry 4.0.

Currently, several authors base their research on Industry 4.0 training using various methods and practices such as an interactive approach (Tran, Yahoui, and Siauve 2019), learning factory (Rybski and Jochem 2016; Schallock et al. 2018; Sudira and Juwanto 2019), a combination of online learning, offline learning and practices in an innovation centre (Yang et al. 2018), among others. Furthermore, authors such as Perini et al. (Perini et al. 2017) consider the importance of Industry 4.0 training evaluation.

Considering this scenario, this research aims to validate an appropriate content to be considered in Industry 4.0 training pointed toward managers not skilled in Industry 4.0 concepts.

In addition to this introduction, which presented a brief background on the theme, this paper has four additional sections. Section 2 presents the theoretical background on the critical design principles of Industry 4.0. Section 3 details the methodological procedures to allow the replication of the study. Section 4 presents the results and associated debates. Section 5 shows the main conclusions and, at last, the list of cited references is presented.

2. Theoretical background

The fourth industrial revolution is preceded by three previous revolutions, the first of which began in 1784. The first industrial revolution, or Industry 1.0, was characterised by the mechanical weaving loom, water and steam power, mechanical production equipment, and its starting point was Henry Cort's invention – a better way of making wrought the iron (Di Nardo, Forino, and Murino 2020; Schwab 2016; Strozzi et al. 2017). The focus in Industry 1.0 had only one dimension – product volume. Demand was greater than production capacity and human activities changed its focal point from agriculture to industrial society (Yin, Stecke, and Li 2018).

The second industrial revolution, or Industry 2.0, started in 1870 and was characterised by mass production assembly lines using electrical energy. Its precursors are Frederick Taylor, Henry Ford, and Taiichi Ohno. Frederick Taylor wrote *The Principle of Scientific Management*, the first publication on modern management theory that conferred on him the nomination of the 'Father of Management'. Henry Ford and Taiichi Ohno practised and extended Taylor's theory to develop mass production assembly lines and the Toyota production system. The focus of Industry 2.0 was twofold: product volume and variety (Schwab 2016; Strozzi et al. 2017; Yin, Stecke, and Li 2018).

The third industrial revolution, or Industry 3.0, started around 1970 and was characterised by technological innovation, such as computers and automation. The appearance of the first programmable logic controller (PLC) marked the beginning of this revolution which enabled the development of flexible production lines. Consequently, it was possible to meet the drastic reduction in average product life cycles demanded by the consumer market. The focus of Industry 3.0 was threefold: volume, variety, and delivery time (Schwab 2016; Strozzi et al. 2017; Yin, Stecke, and Li 2018).

The fourth industrial revolution started around 2010 due to the combination and integration of production technologies and devices, Information and Communication systems, data and services in network infrastructures. This scenario made it possible to link real objects with virtual ones and bring together technological, organisational, and human factors. The flexibility and reconfigurability of this production and the interaction with customers enabled customising goods and services with the same cost-efficiency level as mass production (mass-customisation) (Strozzi et al. 2017; Yin, Stecke, and Li 2018). As mentioned, applying these concepts currently transcends the application in the industrial environment. It is plausible in different contexts, such as improving cities by making them smarter and bringing well-being to society as handled by the ISO 37122:2020.

To investigate the fourth industrial revolution phenomenon in detail and facilitate its understanding, academics identify the main concepts called 'pillars' or fundamentals of Industry 4.0. These 'pillars' play a significant role in digital transformation (Ardito et al. 2019; Ghobakhloo 2018, 2020; Hermann, Pentek, and Otto 2016; Oztemel and Gursev 2020; Wagire, Rathore, and Jain 2020). The manufacturing organisations are applying these concepts in their added value system to change the traditional production systems into intelligent ones with the main purpose of satisfying a demand for customised products at the cost of a mass production process (Cordeiro, Ordóñez, and Ferro 2019; Monostori et al. 2016; Zhong et al. 2017).

Based on a systematic literature review, this research considers twelve 'pillars' of Industry 4.0 as shown in Table 1. A description of each 'pillar' together with the corresponding reference is also presented in Table 1. These 'pillars' will be used later as a starting point in the application of the Delphi Technique.

3. Methodological procedure

A methodological procedure was elaborated based on three stages and followed step-by-step to allow the replicability of this research. Figure 1 presents a methodological framework to facilitate the understanding and presentation of the developed stages.

In stage 1, the preferred reporting items for systematic review and meta-analysis (PRISMA) statement (Moher et al. 2009) oriented the report of the systematic literature review. This statement is widely used to guide the report of systematic literature reviews in various research fields, including the Industry 4.0 subject (Bueno, Godinho Filho, and Frank 2020; de Paula Ferreira, Armellini, and De Santa-Eulalia 2020; Liao et al. 2017). The PRISMA statement consists of a four-phase flow diagram (identification, screening, eligibility, inclusion), and the input data and results obtained in each phase are shown in Figure 1.

In Stage 2, the Delphi technique was structured and applied to validate an appropriate content to be considered in Industry 4.0 training pointed toward managers not skilled in Industry 4.0 concepts. Delphi is a technique that helps the researcher structure and organises several points of view by combining the specialised opinions of a group of panellists. The objective is to provide a consensus

Table 1. Industry 4.0 main concepts.

Item	Main concept	Description	References
1	Business management models impact	Industry 4.0 impacts on business management models, highlighting strategic planning, human resources management, project management, change management, and the importance of intrapreneurship in this new reality	(Arnold, Kiel, and Voigt 2016; Ghobakhloo 2018, 2020; Ibarra, Ganzarain, and Igartua 2018; Müller, Buliga, and Voigt 2018; Oztemel and Gursev 2020; Sony and Naik 2019; Wagire, Rathore, and Jain 2020)
2	Smart factory	Integrated manufacturing of a cyber-physical-human system. In this factory, physical resources present an intelligence that enables them to communicate with each other and human resources	(Ghobakhloo 2018, 2020; Kusiak 2018; Machado, Winroth, and Ribeiro da Silva 2020; Oztemel and Gursev 2020)
3	Service orientation	Networked manufacturing infrastructures used in a shared manner, in which companies communicate needs and capabilities automatically. In this context, production capacity and purchasing needs are considered the company's main assets	(Ghobakhloo 2018; Moghaddam, Silva, and Nof 2015; Oztemel and Gursev 2020; Xu and Ilic 2014)
4	Decentralisation	The capacity of intelligent factory components to work independently and autonomously makes decisions but always according to organisational objectives	(Ghobakhloo 2018, 2020; Lasi et al. 2014)
5	Interoperability	The ability of the cyber-physical-human system such as smart products, smart factories, human resources, and others to connect and communicate with each other and operate together	(Ghobakhloo 2018, 2020; Gilchrist 2016; Lu 2017)
6	Systems integration	Process of bringing subsystems together into a single system so that the resulting system can provide the intended functionality	(Ghobakhloo 2018, 2020; Posada et al. 2015)
7	Modularity	Change in the linear manufacturing concept and its respective planning. Replacement of rigid production models by agile systems that can be adapted according to different scenarios and demands	(Ghobakhloo 2018; Gilchrist 2016; Piran et al. 2017)
8	Virtualisation	Digital replication of the value chain, considering data from the physical system in virtual systems ('digital twin' concept)	(Ghobakhloo 2018, 2020; Tao and Qi 2019)
9	Real-time capability	The ability for data collection and performance of decisions based on new findings within the intended timeframe	(Chen et al. 2017; Ghobakhloo 2018, 2020; Moeuf et al. 2018)
10	Smart products	Products that can communicate and inform valuable data about where they are being manufactured, the current manufacture stage, and those actions necessary to reach the target state	(Ghobakhloo 2018, 2020; Gilchrist 2016)
11	Product personalisation	Ability to reconfigure the product based on changes in customer preferences identified through the assessment and prediction of consumer behaviour	(Ghobakhloo 2018, 2020; Jiang, Ding, and Leng 2016; Oztemel and Gursev 2020)
12	CSR and sustainability impact	Insertion of sustainability and CSR in the context of Industry 4.0	(de Sousa Jabbour et al. 2018; Esteban-Sanchez, de la Cuesta-Gonzalez, and Paredes-Gazquez 2017; Ghobakhloo 2018; Sony and Naik 2019)

Source: The Authors.

to complete the state of knowledge concerning a particular topic (Donohoe and Needham 2009a; Gbededo and Liyanage 2020; Powell 2003). An essential advantage of the Delphi technique is its appliance without presential meetings, enabling the consultant of experts in different regions or with temporal conflicts in the agendas (Donohoe and Needham 2009b; Hanafin et al. 2007; Linstone 1985). There is no specific requirement for the number of panellists, but a quantity between ten to

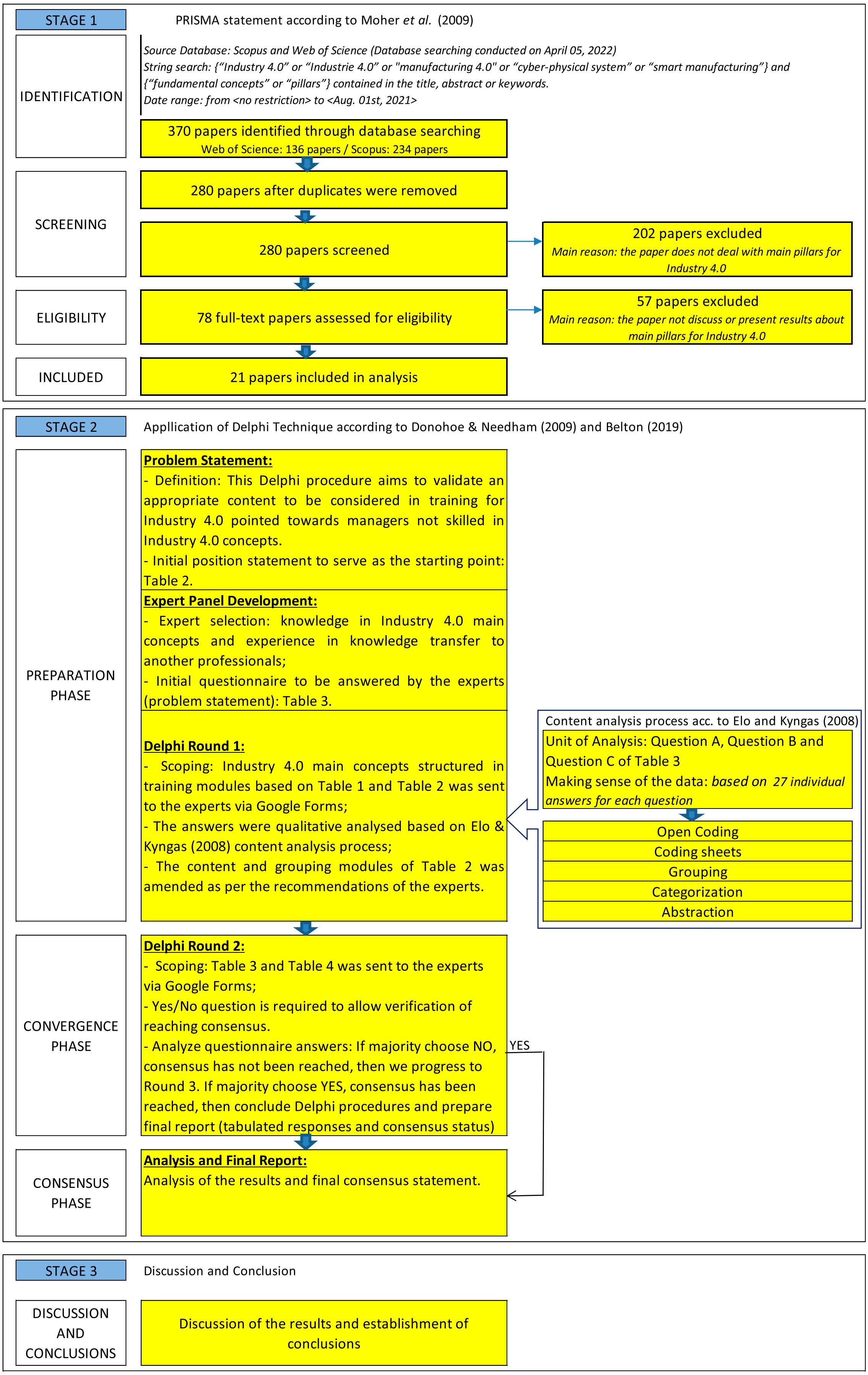

Figure 1. Methodological framework.

Source: The authors.

thirty experts is the most usual. (Belton et al. 2019; de Jesus et al. 2019; Gbededo and Liyanage 2020; Hasson, Keeney, and McKenna 2000; Keeney, Hasson, and Mckenna 2010).

The application of the Delphi technique occurs in rounds, usually two or three rounds (Donohoe and Needham 2009b; Gbededo and Liyanage 2020; Hanafin et al. 2007). Initially, a questionnaire is sent to all panellists and after the receipt of the answers, the moderator performs the analysis and synthesis. Specifically, in this research, an initial structured proposal obtained through a systematic literature review (stage 1) served as a starting point for the panellist's debate, and a content analysis was applied according to Elo and Kyngäs (2008) guidelines.

A new round starts when the analysis and synthesis are sent to each panellist anonymously together with a new questionnaire. Through the rounds, each panellist can see the statements made by other panellists (anonymously) and reflect on them. Facing this new information, the panellist can maintain, complement or change his/her viewpoint. This iterative process allows new themes and ideas to emerge in each round. The rounds occur until a consensus is reached (Brown 2007; Linstone and Turoff 1975). It is fundamental to point out that Ethics Research Committee from State University of Campinas approved this study under number 33444220.6.0000.5404 and data collection started only after this approval and participant consent.

The consensus criterion adopted in this research was that at least 75% of the panellists agreed with the presented data. It is essential to mention that there is no standard criterion for reaching consensus and the consensus criterion mentioned above is based on some authors (Belton et al. 2019; Chang et al. 2010; Gbededo and Liyanage 2020; Keeney, Hasson, and Mckenna 2010). Keeney, Hasson, and Mckenna (2010) considers different levels for agreement – from 100% to 51%; Belton et al. (2019) considers 75% or 80% of agreement; Other authors consider consensus criterion of 75% panellists with the same or similar opinion (Chang et al. 2010; Gbededo and Liyanage 2020).

The Delphi technique performed in this research started with the presentation of Industry 4.0 main concepts structured in training modules based on Table 1 (Delphi Round 1). To prevent each training module from becoming too specific and exhaustive on a given Industry 4.0 main concept, the authors grouped as many as two Industry 4.0 main concepts into one module based on their similarities. The items presented in Table 1 were grouped as follows: Module 1: Business Management Models Impact; Module 2: Smart Factory and Service Orientation; Module 3: Decentralisation and Interoperability; Module 4: Systems Integration and Modularity; Module 5: Virtualisation and Real-Time Capability; Module 6: Smart Products and Product Personalisation; Module 7: CSR and Sustainability Impact. This is an initial consideration made by the authors and placed for panellist discussion.

After analysing Industry 4.0 main concepts and it corresponding modules, the panellists should answer three questions shown in Table 2. These questions are fully open questions in which each panellist could freely express his/her own opinion.

4. Results and discussions

4.1. Panellists characterisation

The selection criteria of experts to participate in the Delphi technique considered their knowledge of Industry 4.0 main concepts, experience related to Industry 4.0 pillars or technological innovations,

Table 2. Delphi Round 1 questionnaire.

Item	Question
A	Considering the training modules individually, the concepts grouping are coherent in terms of proximity?
B	Is (Are) the topic(s) presented in each module adequate? Are there any revision suggestions?
C	Is the sequence of the topics the best one for concepts dissemination? Are there any revision suggestions?

Source: The Authors.

and their experience in transferring this knowledge to other professionals. The experts were chosen through the authors' professional network and professional online network platforms.

So, the group was composed of professors/researchers, consultants and industry professionals. Twenty-seven panellists participated in the first round and twenty panellists continued to participate in the second round. The panellist's characterisation presented in Figures 2–4 consider the twenty experts who participated in the two rounds. Most panellists have a PhD and professional experience in the industry and as university professors or researchers. Specifically, regarding the Industry 4.0 subject, most panellists have 4 years of experience.

4.2. Delphi technique results

In the Delphi Round 1 (preparation phase), the panellists were asked to answer the questions presented in Table 2 based on Industry 4.0 main concepts structured in training modules according to Table 1. Figure 5 presents its results.

Considering percentages, it is possible to note that the agreement is lower than 80% in the three questions and, consequently, no consensus was reached (Belton et al. 2019; Chang et al. 2010; Gbededo and Liyanage 2020; Keeney, Hasson, and Mckenna 2010; Powell 2003). Thus, a new Delphi round is required.

The analysis of individual responses showed three main points of improvement: a more significant focus on the first module, additional details concerning technologies related to Industry 4.0 and adding content referring to the implementation of Industry 4.0. Table 3 presents the revised modules considering the opinion and comments of panellists in Delphi Round 1.

Based on this data, Delphi Round 2 (convergence phase) started with the submission of Table 3 to all the panellists that participated in Delphi Round 1 (27 panellists) along with two new questions presented in Table 4.

From the total of 27, 20 panellists returned the survey. According to several authors (Belton et al. 2019; de Jesus et al. 2019; Gbededo and Liyanage 2020; Hasson, Keeney, and McKenna 2000; Keeney, Hasson, and Mckenna 2010), this is a sufficient number of panellists to carry out a Delphi technique. Figure 6 presents the panellists' responses to question A of Table 4 (multiple-choice question).

In this way, the consensus was reached with the index of 80% (above the criteria of 75%), and we decided not to carry out the next round. The content presented in Table 3 was the final result. In order to clarify the answers of the others four panellists, who answered 'no' in question A of Table 4, they proposed some reordering in some modules and one of them proposed the inclusion of some soft skills. It is essential to mention that soft skills content is included in the first module and the reordering of modules could provide conflict with the majority opinion.

Based on this result, the Industry 4.0 main concepts presented by the academic literature and shown in Table 1, that is, Business Management Models Impact, Smart Factory, Service Orientation, Decentralisation, Interoperability, Systems Integration, Modularity, Virtualisation, Real-Time

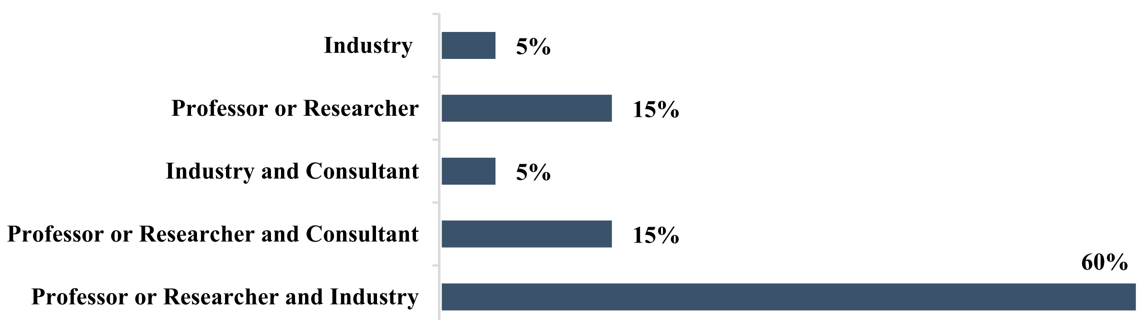

Figure 2. Panellist's classification according to professional activity/experience.
Source: The authors.

Figure 3. Panellist's classification according to academic qualification.
Source: The authors.

Capability, Smart Products, Product Personalisation, and CSR and sustainability impact, are considered relevant in Industry 4.0 training aimed at managers who are unfamiliar with this theme and intend to get a holistic view of it. Furthermore, additional content regarding the implementation of Industry 4.0 was considered essential to be added by the panellists and this content was included in a new module (Module 8).

Furthermore, additional content has been added in the description of some topics. Module 1 – Business Management Model included the impact of Industry 4.0 in the major areas of a company (as quality, sales, logistics, and others) and the impact on the behaviour of a company's employees ('soft skills' and 'digital skills'). Module 3 – Smart Factory included a broad view of additive manufacturing, blockchain, and other related technologies and an introduction about decentralisation and interoperability to support a better understanding of Smart Factory. Module 7 – CSR and Sustainability Impact included content related to circular economy such as traceability during use and disposal of smart products.

Finally, the concepts grouped into modules and their corresponding ordering were revised to provide a better sequence for disseminating the main concepts and coherency in terms of content proximity.

5. Conclusions

This paper aims to validate adequate content for Industry 4.0 training recommended to managers who are unfamiliar with this subject and intend to get a general view of it. A systematic literature review on Industry 4.0 main concepts was used together with experts' perceptions on disseminating Industry 4.0 knowledge. The methodological procedure consisted of applying the Delphi technique in two rounds. In the first round, 27 experts answered the questions and, in the second round, 20 experts answered the questions.

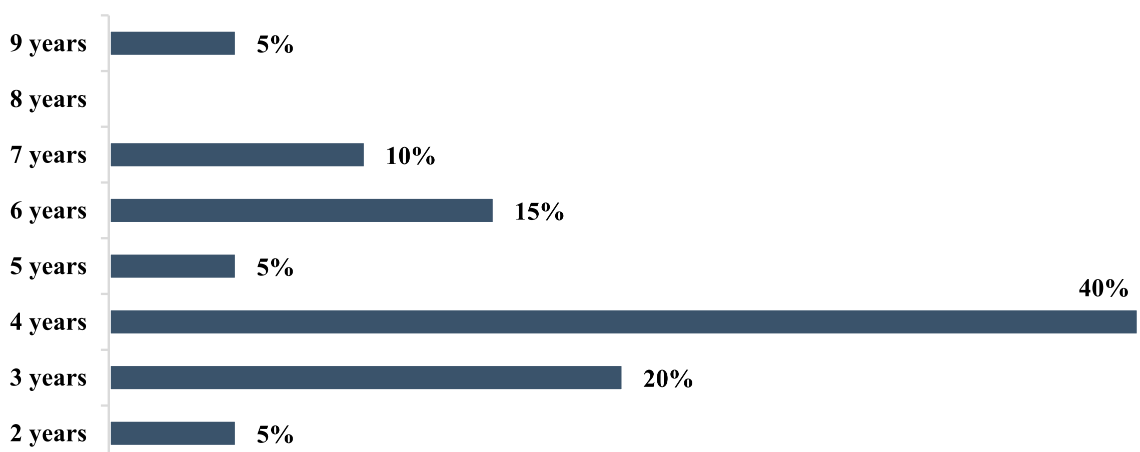

Figure 4. Panellist's classification according to years of experience in Industry 4.0.
Source: The authors.

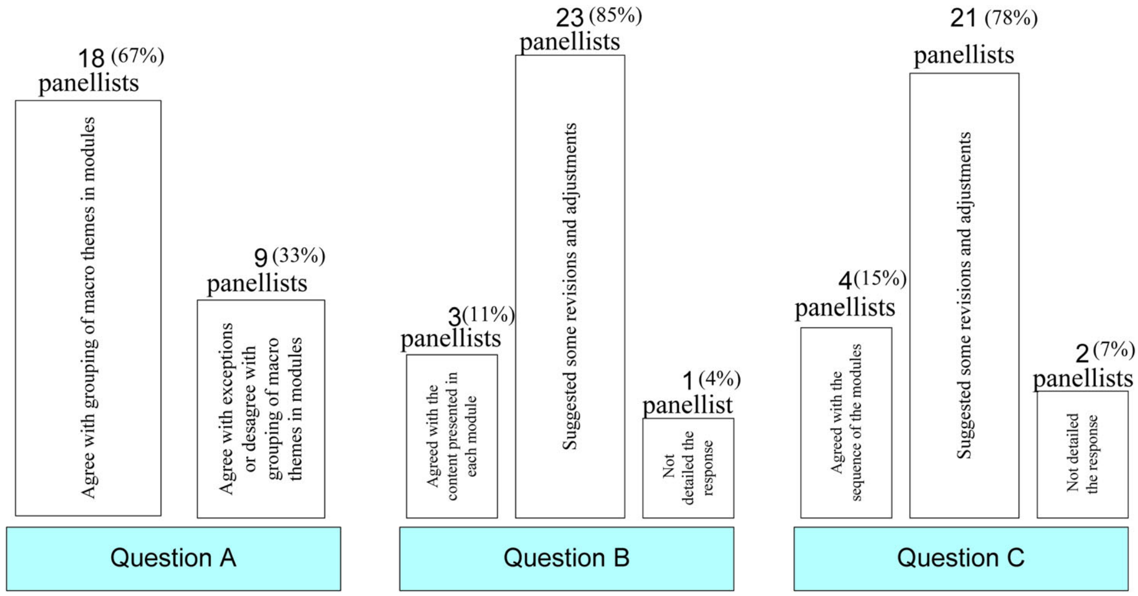

Figure 5. Results of Delphi Round 1.
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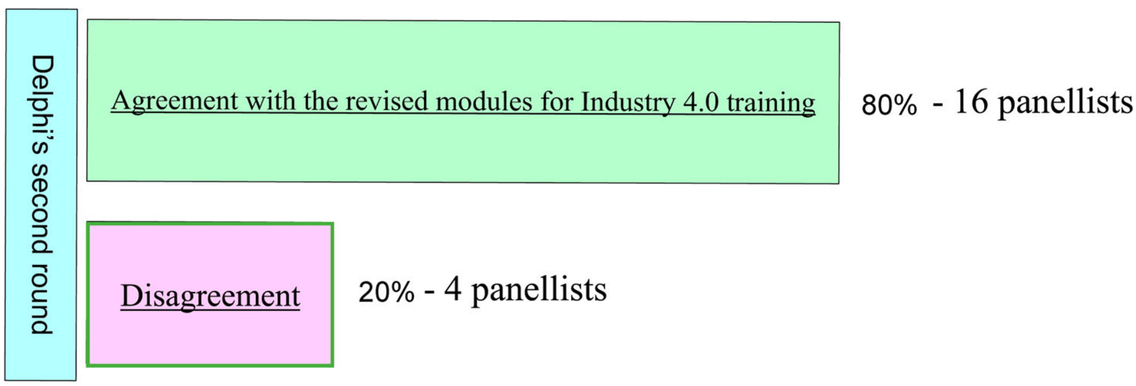

Figure 6. Results of Delphi Round 2.
Source: The authors.

Based on the results, the objective of this paper was reached. According to the panellists, all Industry 4.0 main concepts presented by the systematic literature review are relevant to be included in the training content. It refers to Business Management Models Impact, Smart Factory, Service Orientation, Decentralisation, Interoperability, Systems Integration, Modularity, Virtualisation, Real-Time Capability, Smart Products, Product Personalisation, and CSR and sustainability impact. Additionally, the implementation of Industry 4.0 should be included in the training content.

All these concepts should be grouped into eight modules: (1) Business Management Models Impact, (2) Product Personalisation and Smart Products, (3) Smart Factory and Systems Integration, (4) Modularity and Service Orientation, (5) Decentralisation and Interoperability, (6) Virtualisation and Real-Time Capability, (7) CSR and sustainability Impact and (8) Industry 4.0 Implementation should be considered for Industry 4.0 training purposes in this sequence.

The main limitation of this study is the sample size, since the results considered the perceptions of 27 experts in the first round of the Delphi technique and 20 experts in the second round of the Delphi technique. However, the experts' knowledge should be emphasised and the systematic literature review corroborated the results.

While the authors believe that the results may be useful for academics, consultants, and professionals who need to design courses and training about Industry 4.0 theme, the debate on this

Table 3. Delphi Round 2 revised content and grouping of Industry 4.0 main concepts.

#	Topic	Topic description
Module 1	Business management models impact	Initially, the concept of Industry 4.0 is presented in all its extension considering the characteristics of the digital transformation and a broad view of the principles and technologies that support this transformation. Subsequently, the impact of Industry 4.0 on business management models is discussed highlighting strategic planning, human resources management, project management, change management, intrapreneurship, and agile governance. Also, it is discussed the impact of Industry 4.0 in the major areas of a company as quality, sales, logistics, human resources, and others. Finally, it is discussed the impact of these changes on the behaviour of a company's employees ('soft skills' and 'digital skills').
Module 2	Product personalisation and smart products	Product Personalisation: discuss the meeting of continually changing customer preferences taking benefit from the cyber-physical system (CPS), automation, and additive manufacturing, among other modern technology trends. Smart Products: debate issues related to: (1) communication between products and their respective production machines; (2) products' control over their own production processes.
Module 3	Smart factory and systems integration	Smart Factory: present an overview of new technologies and production processes; automation and automation methodologies and virtualisation applied to the production process: virtual reality, augmented reality, simulations, virtual prototypes, additive manufacturing, blockchain, and other related technologies. Additionally, there is an introduction about decentralisation and interoperability to support the development of this module. Systems Integration: discuss the integration between the 'layers' of systems and technologies, the integration between product and digital production engineering, and the complete integration of the company's value chain – the concept of vertical integration and horizontal integration.
Module 4	Modularity and service orientation	Modularity: debate issues related to modular decision-making procedures for production flexibility. Service Orientation: discuss concepts such as Manufacturing as a Service (MaaS), Cloud Manufacturing, Smart Manufacturing, and Product as a Service (PaaS).
Module 5	Decentralisation and interoperability	Decentralisation: present a broad view of the advantages of decentralisation (speed up decision making, planning and coordination simplification, reduction in organisational hierarchies, among others) and its facilitators (cyber-physical system, intelligent control mechanisms, among others). Interoperability: discuss the integrated digital infrastructure and communication through IIoT (Industrial Internet of Things), IoS (Internet of Service), IoP (Internet of People) and/or WoT (Web of Things). In addition, present the interoperability levels (operational, systematic, technical and semantic).
Module 6	Virtualisation and real-time capability	Virtualisation: debate the concept and application of 'digital twin'. Real-time capability: discuss communication and decision-making in the cyber-physical-human system, as well as 'system integration' and 'decentralisation' as requirements for 'real-time capability'.
Module 7	CSR and sustainability impact	Debate the impact of Industry 4.0 on employment opportunities, labour and social conditions, environment, and sustainable manufacturing. In addition, it present a broad view on sustainability related to new materials, manufacturing processes, energy and pollutants attributed to modern manufacturing, and content related to circular economy such as traceability during use and disposal of smart products.
Module 8	Industry 4.0 implementation	The aim is to present the implementation of the above-mentioned modules and its synergy with other methodologies in execution in a company, such as 'lean production'. Thus, the following items will be discussed: (1) an overview of the maturity stage of Industry 4.0 according to models published in the literature and, (2) Brazilian government Industry 4.0 development initiatives with a presentation of real cases. It is also intended to discuss and identify a company's needs concerning the context of Industry 4.0 and broadly address implementation risks. Finally, resume the discussion on business models based on Module 1.

Search: The Authors.

Table 4. Delphi Round 2 questionnaire.

Item	Question
A	Do you agree with the revised modules for Industry 4.0 training presented in Table 3? (Yes / No)
B	If you disagree with the revised modules for Industry 4.0 training, what changes would be needed? (open-ended question)

Source: The Authors.

subject is by no means exhausted. Further research may consider best training practices that can enhance learning concerning the content validated by this research, ways to improve the assessment of learning for the professionals in training, how continuously improve the training considering future new technologies, and the practical application of this content in training to managers who are not familiar with the Industry 4.0 theme and intend to get a general view about it.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by National Council for Scientific and Technological Development (CNPq) [grant number: 140998/2020-9, 307536/2018-1].

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3 DISCUSSÕES

Tendo-se por base os resultados e discussões apresentados no capítulo anterior de maneira individualizada, o Quadro 1 resume conjuntamente os resultados apresentados nos dois artigos de natureza empírica da tese, a saber *"Main Challenges and Best Practices to Be Adopted in Training for Industry 4.0*" e *"Training for managers not skilled in Industry 4.0 basis: what is the most suitable content to be covered?"*. Nesse caso, o Quadro 1 pode ser interpretado como um conjunto de diretrizes básicas para a concepção e gestão de treinamentos ou programas de desenvolvimento de conhecimentos. Por exemplo, em relação ao conteúdo, os resultados demonstram a necessidade de se abordar noções básicas sobre os pilares da Indústria 4.0 e, adicionalmente, o impacto da Indústria 4.0 nos modelos de gestão de negócios e a intersecção da Indústria 4.0 com outras áreas de relevância na atualidade, como Sustentabilidade e Responsabilidade Social Corporativa (RSC). Adicionalmente, as diretrizes recomendam que se aborde a implementação da Indústria 4.0. Quanto as melhores práticas, foram destacadas ações a serem efetivadas antes, durante e após o treinamento ou programa de desenvolvimento de conhecimentos as quais seguem as principais recomendações de (SALAS *et al.*, 2012, 2015).

Antes da realização do treinamento ou programa de desenvolvimento de conhecimentos, recomenda-se a aplicação de práticas relacionadas ao seu planejamento. Durante a execução, devem ser utilizadas metodologias ativas de aprendizagem, tecnologias integradas como *gamificação*, entre outras. Finalmente, os participantes devem avaliá-lo. A avaliação deve ser elaborada com um propósito claro e ser realizada em quatro níveis: reações, aprendizagem, comportamento e resultados (KIRKPATRICK; KIRKPATRICK, 2006).

Em referência aos desafios, os resultados dessa pesquisa apresentam onze itens, os quais foram agrupados em quatro categorias: relacionados ao conhecimento necessário dos profissionais em treinamento ou em desenvolvimento, relacionados a quebra de paradigmas, relacionados a características e resultados esperados.

Quadro 1. Diretrizes amplas para desenvolvimento de conhecimentos em gestores não familiarizados em Indústria 4.0

DIRETRIZES		**PRINCIPAIS DESAFIOS**
CONTEÚDO	**MELHORES PRÁTICAS**	
1) Impacto dos Modelos de Gestão de Negócios 2) Personalização de Produtos e Produtos Inteligentes 3) Fábrica Inteligente e Integração de Sistemas 4) Modularidade e Orientação a Serviços 5) Descentralização e Interoperabilidade 6) Virtualização e Capacidade em Tempo Real 7) CSR e sustentabilidade 8) Implementação da Indústria 4.0	*Práticas a serem adotadas ANTES do treinamento ou programa de desenvolvimento (planejamento)*	- *Conhecimento necessário:*
	1) Realizar um debate prévio com a diretoria da organização 2) Coletar informações sobre os profissionais em desenvolvimento, incluindo suas competências 3) Analise o cronograma e a duração do treinamento	1) Superar barreiras relacionadas ao conhecimento mínimo necessário de automação, programação, matemática e estatística; 2) Adaptar o conteúdo princípios a serem ensinados considerando a heterogeneidade do grupo em desenvolvimento.
	Práticas a serem adotadas DURANTE o treinamento ou programa de desenvolvimento (execução)	- *Quebra de paradigmas:*
	1) Apresentar regras de participação, políticas da organização, necessidades do treinamento ou programa de desenvolvimento e como o mesmo está alinhado com os objetivos estratégicos da organização 2) Estruturar o conteúdo considerando abordagens pedagógicas 3) Utilizar técnicas que motivem e mantenham os profissionais em desenvolvimento atentos ao conteúdo	1) Romper com a percepção de que a Indústria 4.0 está disponível somente para empresas renomadas ou de grande porte; 2) Tornar evidente que a adoção e implementação da Indústria 4.0 não é um processo rápido e padronizado; 3) Romper com a ideia que a Indústria 4.0 está relacionada somente a tecnologias complexas e tornar clara a necessidade de um modelo para sua implementação;
	4) Utilizar metodologia de aprendizagem ativa 5)Utilizar tecnologias integradas	- *Características do treinamento ou programa de desenvolvimento:* 1) Estruturar a parte teórica sem ser repetitivo em conceitos, princípios e tecnologias; 2) Desenvolver dinâmicas específicas a fim de permitir a prática de conceitos e princípios da Indústria 4.0; 3) Avaliar o entendimento dos conceitos e princípios da Indústria 4.0
	Práticas a serem adotadas APÓS o treinamento ou programa de desenvolvimento (avaliação)	- *Resultados esperados:*
	1) Especificar claramente o propósito de avaliar o treinamento ou programa de desenvolvimento 2) Medir os resultados em quatro níveis: reações, aprendizagem, comportamento e resultados	1) Capacitar os profissionais em desenvolvimento para a identificar a aplicabilidade da Indústria 4.0 nos processos produtivos de suas empresas; 2) Garantir que os profissionais em desenvolvimento possam identificar os ganhos potenciais decorrentes da aplicabilidade da Indústria 4.0; 3) Possibilitar aos profissionais em desenvolvimento refletir sobre o modelo de negócios de suas empresas.

Fonte: Autor

Nota-se que os principais desafios apresentados no Quadro 1 devem estar presentes e serem considerados em conjunto com os outros dois segmentos – conteúdo e melhores práticas. Assim, como exemplo, os principais desafios apresentados no grupo “conhecimento necessário” devem ser considerados na elaboração do conteúdo, principalmente em relação aos pilares da Indústria 4.0, e nas melhores práticas, principalmente naquelas relacionadas ao planejamento e execução do treinamento ou programa de desenvolvimento.

Evidentemente, para um público não familiarizado ou com conhecimento preliminar no assunto, todos os desafios não são supridos em um primeiro momento. Demanda-se um longo tempo para, por exemplo “superar barreiras relacionadas ao conhecimento mínimo necessário de automação, programação, matemática e estatística", mas por outro lado, pode-se começar a romper "com a percepção de que a Indústria 4.0 está disponível somente para empresas renomadas ou de grande porte".

A prática referente a coleta de informações sobre os profissionais em desenvolvimento, incluindo suas competências, está profundamente relacionada ao desafio de adaptar o conteúdo aos princípios a serem ensinados considerando a heterogeneidade do grupo em desenvolvimento. Adicionalmente, os principais desafios apresentados no grupo "resultados esperados" estão intimamente relacionados as melhores práticas de avaliação, e consequentemente, com o conteúdo a ser abordado.

Os desafios relacionados a identificação da aplicabilidade da Indústria 4.0 nos processos produtivos das organizações contribuem com a identificação dos ganhos potenciais decorrentes e possibilitam a reflexão sobre modelos de negócios. Dessa forma, devem orientar a elaboração do conteúdo especialmente nos módulos referentes ao impacto da Indústria 4.0 nos modelos de gestão de negócios, pilares da Indústria 4.0 e sua respectiva implementação e direcionar o propósito de avaliação.

Essas diretrizes e desafios são particularmente importantes considerando-se a atual exigência de novos conhecimentos e competências para os gestores das empresas, impactados pelas mudanças cada vez mais rápidas dos sistemas produtivos devido principalmente a inserção da tecnologia, mudanças de paradigmas ao longo de toda a cadeia produtiva e novos modelos de negócio (ARNOLD; KIEL; VOIGT, 2016; HOU *et al.*, 2020; IBARRA; GANZARAIN; IGARTUA, 2018; MÜLLER; BULIGA; VOIGT, 2018). Esse cenário é especialmente relevante no Brasil, o qual apresenta muitas empresas sem o conhecimento básico sobre Indústria 4.0 (FIESP, 2018; FIRMINO *et al.*, 2020) e com o desenvolvimento retardado da Indústria 4.0 devido a pandemia do COVID-19 (CAZERI *et al.*, 2022).

Sobre o conteúdo proposto e validado acerca da Sustentabilidade e RSC no contexto da Indústria 4.0, vale a pena recordar Lantada (2020), segundo o qual a sustentabilidade e a garantia dos direitos humanos deve orientar a construção de uma sociedade igualitária, valendo-se dos avanços tecnológicos. Há de se destacar ainda que conteúdos mais específicos e diretamente relacionados a Indústria 4.0 podem ser ou não aprofundados pelo profissional que irá ministrar o treinamento ou programa de desenvolvimento depois de realizar uma análise inicial do grupo com o qual irá trabalhar.

Estes exemplos de relações entre principais desafios, melhores práticas e conteúdo são apresentados na Figura 1.

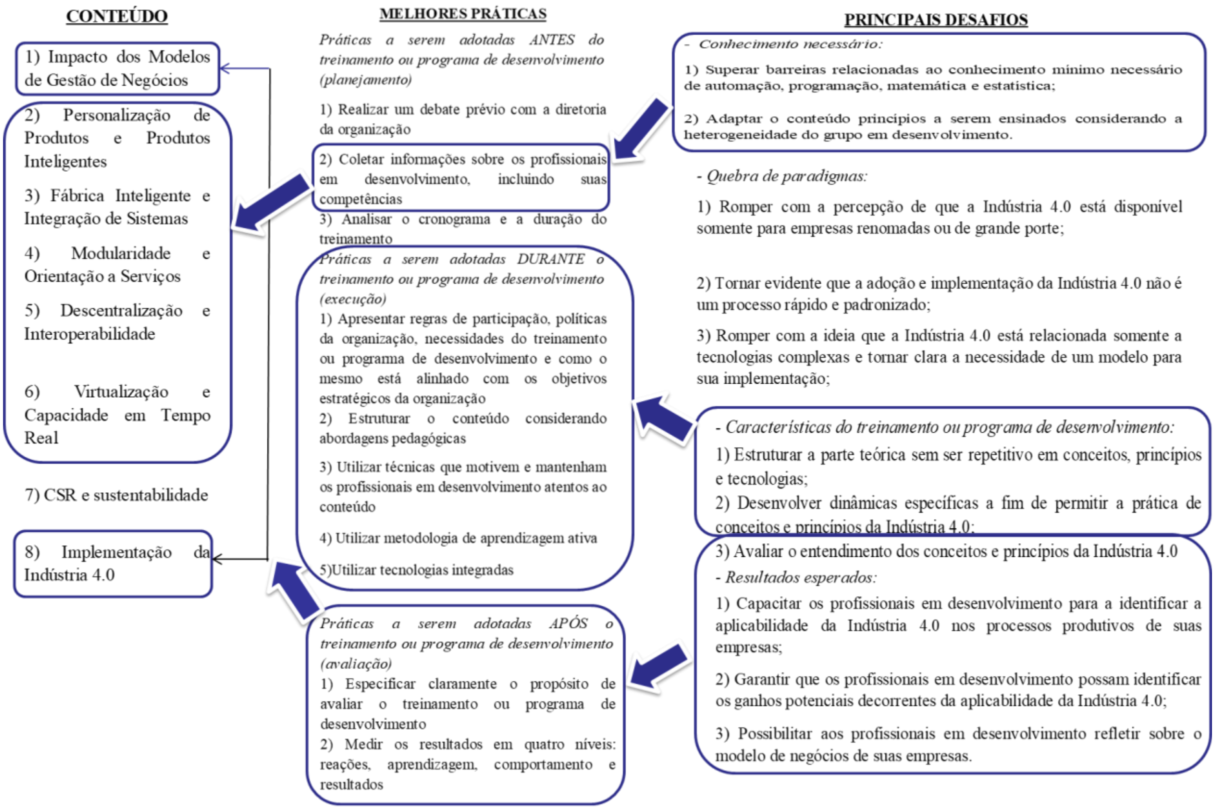

Figura 1. Exemplos de relações entre principais desafios, melhores práticas e conteúdo.
Fonte: Autor

Adicionalmente, essas diretrizes relacionam-se com o ciclo Planejar-Executar-Verificar-Agir ou *Plan-Do-Check-Act* (PDCA). Este ciclo foi inicialmente proposto por Walter Shewart na década de 30 sob a denominação de *Plan-Do-Study-Act* (PDSA) e, posteriormente, foi difundido por Willian Edwards Deming sob a denominação PDCA (DEMING, 2000). Trata-se de um método de gestão utilizado para melhoria de processos e produtos de maneira contínua e iterativa, sendo que na etapa "Planejar" busca-se estabelecer objetivos e os procedimentos que serão utilizados para a obtenção desses objetivos, ou seja, identificar o problema, analisar o fenômeno ou processo e estabelecer um plano de ação. Neste trabalho, relacionam-se com essa etapa as práticas a serem adotadas antes da realização do treinamento ou programa de desenvolvimento, juntamente com os principais desafios e conteúdos associados. A etapa "Executar" refere-se a implementação do plano de ação estabelecido na etapa "Planejar" e, neste trabalho, refere-se a executar o treinamento de acordo com as práticas a serem adotadas durante o treinamento ou programa de desenvolvimento, juntamente com os principais desafios e conteúdo relacionado. A próxima etapa, "Verificar" refere-se a checar se a implementação do plano de ação ocorreu conforme o estabelecido na etapa "Planejar". Neste trabalho, incluem-se nessa etapa as práticas a serem adotadas após a realização do treinamento ou programa de desenvolvimento, ou seja, a avaliação do mesmo pelos profissionais em desenvolvimento, juntamente com os principais desafios e conteúdo associados. Por fim, a etapa “Agir” refere-se a implementar melhorias com base nos dados obtidos na etapa “Verificar”. Neste trabalho, essa etapa significa implementar melhorias nas práticas a serem adotadas antes e durante o treinamento ou programa de desenvolvimento conforme os dados obtidos pela avaliação dos profissionais em desenvolvimento (DEMING, 2000; PALADINI; CARVALHO, 2012). A Figura 2 apresenta a relação das melhores práticas propostas por este trabalho com o ciclo PDCA de forma resumida.

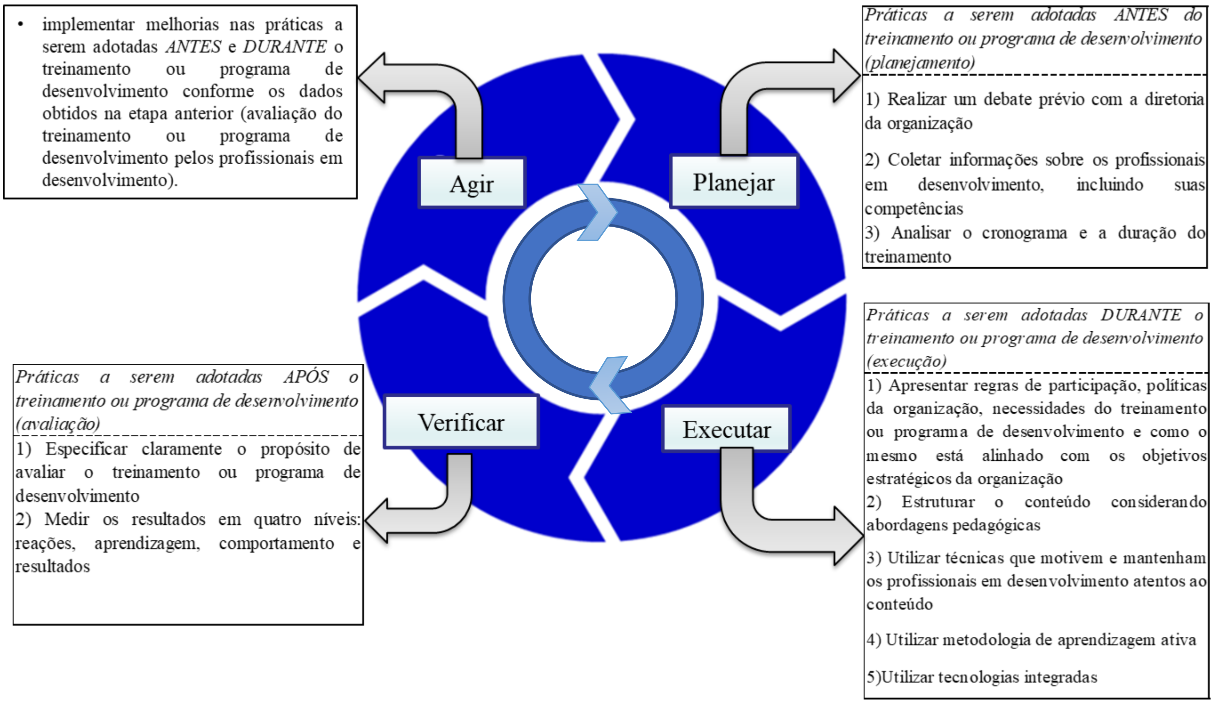

Figura 2 – Relação das melhores práticas propostas por este trabalho com o ciclo PDCA.
Fonte: Autor

Por outro lado, os gestores assumem papel importante no desempenho de uma organização, o qual é estudado desde a Escola Clássica da Administração. Henri Fayol, um dos contribuintes mais importantes do desenvolvimento do conhecimento administrativo moderno, foi o primeiro a reconhecer a administração como uma função separada das demais funções de uma empresa e, como consequência, identificar o trabalho dos gestores como distintos em relação às operações técnicas da organização. Segundo Fayol, o trabalho do dirigente consiste em tomar decisões, estabelecer metas, definir diretrizes e atribuir responsabilidades aos integrantes da organização de modo que as atividades de planejar, organizar, comandar, coordenar e controlar para que estejam numa sequência lógica (FAYOL, 1954; HUSE; BOWDITCH, 1973; ODIORNE, 1965; STONER; FREEMAN; GILBERT, 1995)

Entretanto, Henry Mintzberg ampliou as considerações de Fayol sobre os papéis gerenciais, afirmando que os gestores não têm apenas o papel de planejar, organizar, dirigir e controlar. Essas funções dizem respeito ao processo administrativo, mas os gestores apresentam responsabilidades adicionais na organização em que atuam (MINTZBERG, 1973). Como resultado de anos de pesquisa, apresentou um modelo de gestão que abrange os papéis, as responsabilidades e as competências necessárias a todo gestor. Trata-se de um modelo genérico, uma vez os papéis do trabalho gerencial se aplicam a todos os gerentes em qualquer nível de hierarquia; alterando-se, conforme o contexto de trabalho de cada gerente, a intensidade e a forma de aplicação desses papéis. Ao todo são apresentados dez papéis organizados em três grupos: papéis informacionais (monitor, disseminador e porta voz), papéis interpessoais (representante da empresa, líder e contato) e papéis decisórios (empreendedor, resolvedor de conflitos, alocador de recursos e negociador). A esse conjunto, ele acrescenta ainda os papéis de estruturação e programação do trabalho (MINTZBERG, 2010).

Tendo-se por base esse contexto, foi verificada a coerência deste trabalho à luz de algumas das principais Teorias Gerais da Administração. Foram escolhidas para essa análise a Teoria do Desenvolvimento Organizacional (DO), Teoria Sociotécnica, Teoria da Contingência e Teoria da Ambidestria.

A Teoria do Desenvolvimento Organizacional tem como principal precursor Leland Bradford, o qual apresenta a fusão de duas tendências no estudo das organizações: o estudo da estrutura da organização e o estudo do comportamento humano, integrados através de um tratamento sistêmico (BRADFORD; GIBB; BENNE, 1964). Conforme Beckhard (1969), a teoria do Desenvolvimento Organizacional (DO) visa à clara percepção do que está ocorrendo nos ambientes interno e externo da organização e pode ser entendido como um processo que faz uso de teorias das ciências do comportamento, valores, estratégias e técnicas orientadas às mudanças do ambiente de trabalho, com a intenção de tornar a organização mais eficaz e adaptável às mudanças. As diretrizes e desafios apresentados nessa pesquisa apresentam uma nova visão do ambiente externo na medida em que busca romper com conceitos equivocados sobre Indústria 4.0, como a percepção de que a adoção e implementação da Indústria 4.0 é um processo rápido e padronizado, entre outros e apresenta o impacto da Indústria 4.0 nos modelos de gestão de negócios. Além disso, as diretrizes propostas preconizam um maior conhecimento do ambiente interno da organização, pois recomenda debates com a diretoria sobre os objetivos da organização e coleta informações sobre os profissionais em desenvolvimento, incluindo suas competências. Adicionalmente, as diretrizes e desafios apresentados impactam na cultura organizacional e clima organizacional, discutindo novas crenças e valores em termos de sustentabilidade, RSC e modelos de gestão e promovem dinâmicas específicas a fim de permitir a prática e implementação de conceitos e princípios da Indústria 4.0. Segundo Glisson (2007), Iljins; Skvarciany; Gaile-Sarkane (2015) e Meyer *et al.* (2010), a mudança na cultura e clima organizacional está ligada a quatro fatores principais: adaptabilidade, senso de identidade, perspectiva exata do meio ambiente e integração entre os participantes. Nota-se que esses quatro fatores estão presentes nas diretrizes e desafios apresentados, uma vez que os mesmos desenvolvem a capacidade de resolver problemas e de reagir de maneira flexível às exigências mutáveis e inconstantes do meio ambiente (adaptabilidade), promovem o conhecimento e a compreensão do passado e do presente da organização e o compartilhamento de seus objetivos (senso de identidade), a percepção realista e a capacidade de e compreender o meio ambiente (perspectiva exata do meio ambiente) e promovem a integração entre os participantes a fim de que a organização possa se comportar como um todo orgânico e integrado. Verifica-se também que os resultados apresentados por essa pesquisa estão alinhados a um ambiente orientado para mudanças.

A DO considera o processo de mudança em três etapas (descongelamento, mudança e recongelamento) em um campo dinâmico de forças positivas e negativas conforme proposto por Lewin (1965) e Schein (1972). As diretrizes e desafios apresentados por essa pesquisa atuam como forças positivas de apoio e suporte as mudanças na etapa do descongelamento, tornando clara a necessidade de mudança organizacional a ponto de os profissionais poderem facilmente enxergá-la e aceitá-la. O fato das diretrizes apresentadas atuarem como forças positivas é relevante pois, conforme Lewin (1965) e Schein (1972), para que mudanças organizacionais sejam bem-sucedidas é preciso que as forças positivas se sobreponham às forças negativas.

Os resultados desse trabalho também se relacionam positivamente com as recomendações da Teoria Sociotécnica. Inicialmente proposto por Rice (1958), essa teoria adota um sistema aberto com interação mútua e recíproca entre o subsistema técnico (exigências de tarefa, ambiente físico, equipamento disponível) e social (sistema de relações entre aqueles que realizam a tarefa). Segundo Alves da Silva *et al.* (2020), a abordagem sociotécnica é crucial para análise das transições e mudanças de forma ampla e não as reduz apenas a um desafio técnico de implementação, ou as considera impulsionadas exclusivamente por um determinado aspecto, como por exemplo, o financeiro. Na abordagem sociotécnica, as transições também envolvem processos sociais, políticos, culturais, e mudanças nas práticas de consumo. Os resultados dessa pesquisa relacionam-se aos dois subsistemas, sendo o subsistema técnico relacionado ao conteúdo discutido nos pilares da Indústria 4.0, como Fábrica Inteligente, Integração de Sistemas, Modularidade, Descentralização, Produtos Inteligentes, Personalização de produtos, entre outros. No tocante ao subsistema social, podem ser citados a inclusão de conteúdo referente ao impacto das mudanças provocadas pela Indústria 4.0 no comportamento dos colaboradores ('soft skills' e 'digital skills' – módulo 1 "Impacto dos Modelos de Gestão de Negócios"), coleta de informações sobre os profissionais em desenvolvimento (incluindo suas competências) e realização um debate prévio com a diretoria da organização para um planejamento adequado do programa de desenvolvimento, entre outros.

Os resultados dessa pesquisa também foram discutidos à luz da Teoria da Contingência. Seus precursores investigaram a relação da organização com o ambiente, mostrando a existência de uma relação funcional do tipo *se-então* entre as condições do ambiente e as técnicas administrativas apropriadas para o alcance eficaz dos objetivos da organização (BURNS; STALKER, 1961; LAWRENCE; LORSCH, 1967; WOODWARD, 1965). Essa teoria considera que as dimensões internas de uma organização são dependentes das interfaces com o ambiente externo, ou seja, não há uma única e melhor forma ("*the best way*") de organizar e estruturar uma organização. Assim, torna-se relevante a identificação constante e de forma proativa das condições ambientais e das práticas administrativas para que sempre estejam em sintonia (DONALDSON, 1998). Especificamente em relação a essa pesquisa, há a proposição de um conteúdo e melhores práticas de maneira ampla – e, por isso são chamadas de diretrizes, as quais podem ser detalhadas e aprofundadas conforme o tipo de organização e características específicas do público-alvo no qual o treinamento ou programa de desenvolvimento está inserido. As melhores práticas de planejamento, como realizar um debate prévio com a diretoria da organização e coletar informações sobre os profissionais em desenvolvimento, incluindo suas competências, tem a função de conhecer o ambiente em que o treinamento ou programa de desenvolvimento será inserido para assim planejá-lo de forma adequada. Apresenta-se, dessa forma, uma relação funcional entre as condições do ambiente e a elaboração detalhada do programa de desenvolvimento de forma contingente (formação contingencial).

Por fim, os resultados dessa pesquisa foram examinados em relação a Teoria da Ambidestria Organizacional, conceito relacionado a realizar bem duas atividades distintas (DUNCAN, 1976). Trata-se de um tema de pesquisa relativamente novo que vem recebendo contribuições de diversas áreas, como aprendizagem organizacional, inovação, gestão estratégica, design organizacional e adaptação organizacional (NOSELLA; CANTARELLO; FILIPPINI, 2012; TUSHMAN; O´REILLY, 1996). Tem por base analisar a organização por meio de dualidades contraditórias, como *exploration* e *exploitation*. O *exploration* refere-se à mudanças disruptivas e revolucionárias advindas da pesquisa, experimentação ou descoberta, enquanto o *exploitation* envolve mudanças incrementais, refinamento ou eficiência. Assim, a ambidestria é a capacidade organizacional de perseguir ao mesmo tempo o *exploration* e o *exploitation* (CHAKMA; PAUL; DHIR, 2021; MARCH, 1991). Nota-se que as diretrizes e desafios apresentados por essa pesquisa relacionam-se tanto com o *exploration* como o *exploitation*. Em relação ao *exploration,* as diretrizes tratam de um desenvolvimento e exploração de novas ideias e conceitos de forma disruptiva ou revolucionária. Por outro lado, os profissionais em desenvolvimento são estimulados a olhar para a situação atual na qual a organização em que atuam está inserida para que, a partir do reconhecimento do que está implementado e vigente na organização, possam identificar os ganhos potenciais decorrentes da aplicabilidade da Indústria 4.0 de forma incremental tendo por base o nível gerencial em que atuam.

4 CONCLUSÕES E CONSIDERAÇÕES FINAIS

O objetivo desta pesquisa caracteriza-se por propor diretrizes amplas para a disseminação de conceitos relacionados à Indústria 4.0 para gestores de empresas de manufatura não familiarizados nos referidos conceitos, tema este evidenciado como uma lacuna na literatura acadêmica. Para o alcance do objetivo mencionado, foram realizadas pesquisas versando sobre a identificação de melhores práticas para a realização de treinamentos no tema, os principais desafios nas conduções dos mesmos e a validação dos conteúdos mais adequados.

Por meio dos resultados apresentados, conclui-se que em relação às melhores práticas apresentadas pela literatura acadêmica, exceto uma delas mostrou-se inadequada para desenvolvimento de gestores em Indústria 4.0. No que se refere aos principais desafios, os mesmos foram agrupados em quatro categorias e, sendo duas delas (conhecimento necessário dos profissionais em desenvolvimento e quebra de paradigmas) particularmente alinhadas a realidade brasileira de gestores não familiarizados em Indústria 4.0. Para os conteúdos validados e considerados essenciais no treinamento ou programas de desenvolvimento dos gestores, estes incluem não somente conhecimentos associados às tecnologias e ferramentas, mas também aspectos como o impacto nos modelos de negócio das empresas, a relação entre sustentabilidade, tecnologia e digitalização e formas de realizar a implementação dos conceitos em questão. Dessa forma, os resultados desta pesquisa podem ser utilizados por profissionais, acadêmicos ou consultores no planejamento, execução e aprimoramento de programas de desenvolvimento direcionados a Indústria 4.0 bem como por outros pesquisadores em seus estudos.

Os métodos utilizados na pesquisa e a qualificação dos especialistas que participaram da pesquisa mostraram-se adequados frente ao atual estágio de desenvolvimento do conhecimento sobre treinamentos ou programas de desenvolvimento para Indústria 4.0, entretanto há limitações na pesquisa em questão já que a escolha de outros métodos associados a consulta de diferentes especialistas pode conduzir a percepções um pouco diferentes. Adicionalmente, e embora a amostra de especialistas que participaram dessa pesquisa tenha sido suficiente para propor diretrizes amplas destinadas a disseminação de conceitos relacionados à Indústria 4.0, é importante que as mesmas sejam avaliadas empiricamente. Trata-se de um item incluso na proposta de futuras pesquisas.

Como propostas para pesquisas futuras, apontam-se:

a) Aplicar as diretrizes aqui apresentadas em diferentes empresas de manufatura para sua validação sob o ponto de vista prático;

b) Ampliar os resultados deste trabalho considerando diretrizes para o desenvolvimento de gestores em Indústria 5.0;

c) Aprofundar a análise da relação entre as diretrizes apresentadas neste trabalho com o ciclo PDCA, objetivando-se a proposição de um modelo genérico para programas de desenvolvimento ou treinamento;

d) Aprofundar a análise da relação entre as diretrizes apresentadas neste trabalho com as Teorias Gerais da Administração, como o DO, Abordagem Sociotécnica, Teoria da Contingência, Ambidestria Organizacional, entre outras.

e) Estender a aplicação das diretrizes apresentadas neste trabalho para gestores com conhecimentos avançados em Indústria 4.0, mas que se percebam não familiarizados em algum ou alguns dos módulos de conteúdo. Para tal, propõe-se a criação de rotas ou trilhas de aprendizagem a fim de possibilitar a aplicação parcial do programa de desenvolvimento ou treinamento.

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ANEXO 1 - Autorizações Comitê de Ética em Pesquisa

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PARECER CONSUBSTANCIADO DO CEP

DADOS DA EMENDA

Título da Pesquisa: Proposição de um método de treinamento para a disseminação de conceitos relacionados à Indústria 4.0

Pesquisador: Gustavo Tietz Cazeri

Área Temática:

Versão: 3

CAAE: 33444220.6.0000.5404

Instituição Proponente: Faculdade de Engenharia Mecânica

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 4.435.317

Apresentação do Projeto:

Trata-se de uma emenda que visa solicitar alterações no protocolo de pesquisa devido a pandemia. Nesta versão os pesquisadores propõem a coleta de dados de forma online, no qual os participantes responderão a algumas perguntas iniciais e depois participarão de um método Delphi. Os pesquisadores apresentaram o novo TCLE que será aplicado de forma online, alteração do título, cronograma, riscos, adequação dos objetivos e tamanho amostral.

Objetivo da Pesquisa:

A presente pesquisa tem por objetivo propor um método de treinamento sobre conceitos da Indústria 4.0 voltado a gestores que não estejam inteirados ao tema e desejam obter uma visão ampla do assunto. A presente solicitação apresentada ao Comitê de Ética em Pesquisa (CEP) visa receber a aprovação para coleta de dados junto a especialistas. Futuramente, almeja-se ofertar o treinamento em uma empresa e, para tal, uma emenda será colocada no momento oportuno.

Avaliação dos Riscos e Benefícios:

Entendemos que para esta pesquisa os riscos não são previsíveis, uma vez que se trata de uma coleta de dados junto a especialistas envolvendo "opiniões" sobre métodos de treinamentos relacionados ao tema indústria 4.0. O tempo estimado para análise e atribuição de respostas a cada rodada é de 20 minutos e as mesmas acontecerão com intervalo de 10 dias. Entretanto, caso sinta qualquer tipo de desconforto, o participante tem o direito de não participar da pesquisa e procurar os pesquisadores para esclarecer dúvidas. A via do TCLE pode ser salva pelo participante através do link designado.

Comentários e Considerações sobre a Pesquisa:

De acordo com as informações do pesquisador responsável contempladas o documento anexado "Justificativa_EMENDA.pdf 05/11/2020 13:41:36":

"No projeto aprovado, estava previsto um debate a ser realizado entre todos os participantes de forma online em um único dia, em um mesmo horário. A duração prevista para o referido debate era de duas horas. Inúmeras tentativas foram feitas de forma a conseguir uma agenda comum entre todos aqueles que desejavam participar da pesquisa, entretanto, frente à quantidade de membros e diferenças de disponibilidade, não foi possível realizar o debate. Posteriormente ao debate, seriam realizadas entrevistas para avaliar a ênfase que deveria ser dada a cada módulo do treinamento, mas com a pandemia da Covid19, isso parece estar se tornando cada vez mais difícil.

Frente ao atraso da pesquisa, em função da pandemia, optou-se pela realização de um processo mais abrangente, realizado de forma totalmente online, no qual os participantes responderão a algumas perguntas iniciais e depois participarão de um método Delphi. Acredita-se que a realização deste novo processo online, incluindo o método Delphi, tornará mais factível a pesquisa pois o participante poderá responder às perguntas no momento que julgar mais adequado e não precisa ajustar sua agenda para um horário pré-determinado. Tudo será realizado através da plataforma Google Forms.

Em relação às perguntas, os participantes deverão: 1) indicar algumas informações que permitirão conhecer suas experiências no assunto; 2) responder quais acreditam ser os principais desafios para a realização de um treinamento sobre conceitos da Indústria 4.0 voltado a gestores de empresas que não estejam inteirados ao tema e desejam obter uma visão ampla sobre o assunto; 3) a partir de uma lista de práticas de treinamentos organizacionais listadas a partir da literatura, indicar o nível de relevância da mesma para o treinamento proposto.

Em relação ao método Delphi, a primeira rodada consiste na apresentação de uma proposição inicial de módulos estruturados a partir da literatura e os respondentes deverão apresentar opiniões tomando por base suas experiências sobre: 1) o agrupamento de conceitos da Indústria 4.0 em cada módulo; 2) os tópicos que farão parte de cada módulo e 3) a ordenação para apresentação dos módulos.

Findada a primeira rodada do método Delphi, o pesquisador irá analisar os comentários, gerar uma síntese e apresentá-la aos participantes (segunda rodada). Nesta segunda rodada, cada participante terá uma visão geral acerca dos comentários realizados na rodada anterior, sem

conhecer sobre a autoria dos mesmos, e poderá refletir sobre seu ponto de vista - complementá-lo ou até mesmo alterá-lo. Rodadas subsequentes vão sendo abertas conforme a necessidade. Ao longo do processo, o pesquisador melhorará a proposição inicial dos módulos valendo-se das informações que forem pertinentes, viáveis e dentro do escopo do método. Atualizações serão apresentadas nas rodadas subsequentes e colocadas para análise e reflexões. Assim que uma estrutura for validada pela maioria, os participantes indicarão a ênfase que deverá ser dada a cada módulo e, neste momento, análises quantitativas de dados poderão ser utilizadas.
Assim sendo, solicita-se ao CEP aprovação desta emenda para que o processo possa ter início."

Considerações sobre os Termos de apresentação obrigatória:
Na avaliação desta emenda foram analisados os seguintes documentos anexados:
1-PB_INFORMAÇÕES_BÁSICAS_1653947_E1.pdf 28/11/2020 00:35:38;
2-Questionario_EMENDA.pdf 05/11/2020 13:42:28;
3-Justificativa_EMENDA.pdf 05/11/2020 13:41:36;
4-Projeto_CEP_EMENDA_Rev1.pdf 28/11/2020 00:29:10;
5-TCLE_26_11_2020_EMENDA_Rev1.pdf 28/11/2020 00:30:50;
6-Folha_de_Rosto.pdf 05/11/2020 13:37:28;
7-Carta_Resposta_EMENDA.pdf 28/11/2020 00:31:28

Recomendações:
A Comissão Nacional de Ética em Pesquisa (Conep), do Conselho Nacional de Saúde (CNS) orienta a adoção das diretrizes do Ministério da Saúde (MS) decorrentes da pandemia causada pelo Coronavírus SARS-CoV-2 (Covid-19), com o objetivo de minimizar os potenciais riscos à saúde e a integridade dos participantes de pesquisas e pesquisadores.
De acordo com carta circular da CONEP intitulada “ORIENTAÇÕES PARA CONDUÇÃO DE PESQUISAS E ATIVIDADE DOS CEP DURANTE A PANDEMIA PROVOCADA PELO CORONAVÍRUS SARS-COV-2 (COVID-19)” publicada em 09/05/2020, referente ao item II. “Orientações para Pesquisadores”:
- Aconselha-se a adoção de medidas para a prevenção e gerenciamento de todas as atividades de pesquisa, garantindo-se as ações primordiais à saúde, minimizando prejuízos e potenciais riscos, além de prover cuidado e preservar a integridade e assistência dos participantes e da equipe de pesquisa.
- Em observância às dificuldades operacionais decorrentes de todas as medidas impostas pela pandemia do SARS-CoV-2 (COVID- 19), é necessário zelar pelo melhor interesse do participante da pesquisa, mantendo-o informado sobre as modificações do protocolo de pesquisa que possam afetá-lo, principalmente se houver ajuste na condução do estudo, cronograma ou plano de

trabalho.
- Caso sejam necessários a suspensão, interrupção ou o cancelamento da pesquisa, em decorrência dos riscos imprevisíveis aos participantes da pesquisa, por causas diretas ou indiretas, caberá aos investigadores a submissão de notificação para apreciação do Sistema CEP/Conep.
- Nos casos de ensaios clínicos, é permitida, excepcionalmente, a tramitação de emendas concomitantes à implementação de modificações/alterações no protocolo de pesquisa, visando à segurança do participante da pesquisa, assim como dos demais envolvidos no contexto da pesquisa, evitando-se, ainda, quando aplicável, a interrupção no tratamento dos participantes da pesquisa. Eventualmente, na necessidade de modificar o Termo de Consentimento Livre e Esclarecido (TCLE), o pesquisador deverá proceder com o novo consentimento, o mais breve possível.

Conclusões ou Pendências e Lista de Inadequações:
Aprovado.

Considerações Finais a critério do CEP:
- O participante da pesquisa deve receber uma via do Termo de Consentimento Livre e Esclarecido, na íntegra, por ele assinado (quando aplicável).

- O participante da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (quando aplicável).

- O pesquisador deve desenvolver a pesquisa conforme delineada no protocolo aprovado. Se o pesquisador considerar a descontinuação do estudo, esta deve ser justificada e somente ser realizada após análise das razões da descontinuidade pelo CEP que o aprovou. O pesquisador deve aguardar o parecer do CEP quanto à descontinuação, exceto quando perceber risco ou dano não previsto ao participante ou quando constatar a superioridade de uma estratégia diagnóstica ou terapêutica oferecida a um dos grupos da pesquisa, isto é, somente em caso de necessidade de ação imediata com intuito de proteger os participantes.

- O CEP deve ser informado de todos os efeitos adversos ou fatos relevantes que alterem o curso

Endereço: Rua Tessália Vieira de Camargo, 126
Bairro: Barão Geraldo **CEP:** 13.083-887
UF: SP **Município:** CAMPINAS
Telefone: (19)3521-8936 **Fax:** (19)3521-7187 **E-mail:** cep@fcm.unicamp.br

normal do estudo. É papel do pesquisador assegurar medidas imediatas adequadas frente a evento adverso grave ocorrido (mesmo que tenha sido em outro centro) e enviar notificação ao CEP e à Agência Nacional de Vigilância Sanitária – ANVISA – junto com seu posicionamento.

- Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas e aguardando a aprovação do CEP para continuidade da pesquisa. Em caso de projetos do Grupo I ou II apresentados anteriormente à ANVISA, o pesquisador ou patrocinador deve enviá-las também à mesma, junto com o parecer aprovatório do CEP, para serem juntadas ao protocolo inicial.

- Relatórios parciais e final devem ser apresentados ao CEP, inicialmente seis meses após a data deste parecer de aprovação e ao término do estudo.

-Lembramos que segundo a Resolução 466/2012 , item XI.2 letra e, "cabe ao pesquisador apresentar dados solicitados pelo CEP ou pela CONEP a qualquer momento".

-O pesquisador deve manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período de 5 anos após o término da pesquisa.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_1653947_E1.pdf	28/11/2020 00:35:38		Aceito
Outros	Carta_Resposta_EMENDA.pdf	28/11/2020 00:31:28	Gustavo Tietz Cazeri	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_26_11_2020_EMENDA_Rev1.pdf	28/11/2020 00:30:50	Gustavo Tietz Cazeri	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_CEP_EMENDA_Rev1.pdf	28/11/2020 00:29:10	Gustavo Tietz Cazeri	Aceito
Outros	Questionario_EMENDA.pdf	05/11/2020 13:42:28	Gustavo Tietz Cazeri	Aceito
Outros	Justificativa_EMENDA.pdf	05/11/2020	Gustavo Tietz	Aceito

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Continuação do Parecer: 4.435.317

Outros	Justificativa_EMENDA.pdf	13:41:36	Cazeri	Aceito
Folha de Rosto	Folha_de_Rosto.pdf	05/11/2020 13:37:28	Gustavo Tietz Cazeri	Aceito
Outros	Carteira_Unicamp.pdf	10/06/2020 12:56:47	Gustavo Tietz Cazeri	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

CAMPINAS, 03 de Dezembro de 2020

Assinado por:
Renata Maria dos Santos Celeghini
(Coordenador(a))

Endereço: Rua Tessália Vieira de Camargo, 126
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PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Proposição de um método de treinamento para a disseminação de conceitos relacionados à indústria 4.0 em nível gerencial

Pesquisador: Gustavo Tietz Cazeri

Área Temática:

Versão: 1

CAAE: 33444220.6.0000.5404

Instituição Proponente: Faculdade de Engenharia Mecânica

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 4.111.235

Apresentação do Projeto:

As informações contidas nos campos "Apresentação do Projeto", "Objetivo da Pesquisa" e "Avaliação dos Riscos e Benefícios" foram obtidas dos documentos apresentados para apreciação ética e das informações inseridas pelo Pesquisador Responsável do estudo na Plataforma Brasil.

O termo Indústria 4.0 origina-se do termo similar em alemão, “Industrie 4.0”, o
qual foi introduzido pela primeira vez em 2011 na Feira de Hannover. A partir desse evento, esse termo passou a ser cada vez mais utilizado e rapidamente passou a fazer parte de uma estratégia nacional alemã. Nos últimos anos, a Indústria 4.0 tornou-se um assunto comum em organizações multinacionais e, de maneira especial, para a indústria de manufatura e para a indústria da informação. A incorporação da inovação tecnológica ocorre no setor de manufatura de uma organização tanto quanto (se não mais do que) em qualquer outro setor da organização. Assim, o termo Indústria 4.0 pode ser entendido como uma abrangente digitalização e ligação entre os processos produtivos de uma organização. Essa digitalização e ligação ocorre desde o início do processo produtivo (colocação do pedido pelo cliente), passa pela criação e execução do processo produtivo e segue até a entrega do produto final ao cliente. Indústria 4.0 considera-se como a aplicação de sistemas físicos e cibernéticos na produção industrial. Computadores interconectados, materiais inteligentes e máquinas
inteligentes comunicam-se entre si, interagem com o meio ambiente e tomam decisões

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com mínimo envolvimento humano. Esse novo cenário do processo produtivo oferece diversas vantagens como aumento da produtividade, melhor eficiência dos recursos disponíveis e redução na geração de resíduos. Por outro lado, há impactos significativos sob a perspectiva do desenvolvimento social. Diversos autores consideram que a digitalização e a implementação de tecnologias como robôs inteligentes, veículos autônomos, soluções em nuvem e muitas outras devem eliminar empregos menos qualificados e criar oportunidades de emprego em áreas como engenharia de automação, projeto de sistema de controle, aprendizado de máquina e softwares engenharia. Com o objetivo de investigar detalhadamente o fenômeno Indústria 4.0 e facilitar sua compreensão, especialistas identificam os principais conceitos relacionados a Indústria 4.0, chamados de "pilares" ou fundamentos da Indústria 4.0, e as principais tecnologias que atualmente suportam a aplicação desses pilares. Autores identificam e descrevem, através de revisões sistemáticas da literatura,

os pilares e tecnologias da Indústria 4.0. Nesse trabalho são considerados doze (12) pilares e catorze (14) tecnologias da Indústria 4.0. Adicionalmente, é importante salientar que esses conceitos e tecnologias, intrinsecamente ligados a Indústria 4.0, tem resultado em novos modelos de negócio. Diante desse novo cenário, que visa combinar todos os agentes de produção (máquinas, robôs e operadores) por meio de redes de conexões e gerenciamento da informação na forma de sistemas ciber-físicos, torna-se imperativo a existência de treinamentos referentes a disseminação de conceitos relacionados a Indústria 4.0 em uma organização. Os três fatores críticos de sucesso mais importantes para implementação da Indústria 4.0 em uma organização estão ligados as pessoas. Os fatores críticos, em ordem decrescente de importância, são: alinhar as iniciativas da Indústria 4.0 com estratégia organizacional; apoio incondicional da alta direção para as iniciativas da Indústria 4.0 e importância dos colaboradores para o sucesso da Indústria 4.0. Um estudioso da área reforça esse contexto, declarando que a Indústria 4.0 é mais do que apenas tecnologia e que recursos humanos poderão ser mais importantes que a tecnologia nesse ambiente. Assim, o treinamento para a Indústria 4.0 deve abranger três categorias de habilidades:

- Habilidades técnicas, como por exemplo instalar e operar dispositivos de
Tecnologia da Informação;
- Habilidades de transformação, como por exemplo propor e realizar mudanças
nos estágios do sistema de produção;
- Habilidades sociais, como por exemplo trabalho em equipe, transferência de
conhecimento, aquisição de conhecimento, colaboração para sincronização de processos,
entre outros.

Como consequência, treinamentos para profissionais ligados a Industria 4.0 devem conter diferentes abordagens como seminários clássicos, jogos de negócios e estudo de casos práticos.

Objetivo da Pesquisa:

A presente pesquisa tem por objetivo propor de um método de treinamento para a disseminação de conceitos relacionados à indústria 4.0 em nível gerencial. A presente solicitação apresentada ao Comitê de Ética em Pesquisa (CEP) visa receber a aprovação para realização de duas atividades da pesquisa, a saber: debate junto a especialistas e entrevistas junto a profissionais da indústria 4.0.

Futuramente, almeja-se ofertar o treinamento em uma empresa e, para tal, uma ementa será colocada no momento oportuno.

Avaliação dos Riscos e Benefícios:

Segundo o pesquisador este projeto não apresenta riscos previsíveis para os participantes, pois trata-se apenas de debates e entrevistas on line.

Não há benefícios diretos relacionados a essa pesquisa. O grande benefício social associado a esta pesquisa está relacionado à contribuição para o conhecimento científico na área de treinamento e indústria 4.0. Além disso, os resultados decorrentes da mesma poderão motivar pesquisas futuras.

Comentários e Considerações sobre a Pesquisa:

Trata-se de um projeto de Doutorado da Faculdade de Engenharia Mecânica da Unicamp. Pesquisador:Gustavo Tietz Cazeri; Orientador: Prof. Dr. Rosley Anholon desta Faculdade. Co-orientador: Prof. Ph.D. Luis Antonio de Santa-Eulalia (processo de coorientação em andamento na FEM). Relevante para a area, este projeto possui duas etapas: 1) - Realização de um debate com 04 especialistas da área em Indústria 4.0; 2) - Realização de entrevistas com 30 profissionais especialistas da área em Industria 4.0. Os resultados decorrentes do debate e das entrevistas contribuirão para a proposição do método de treinamento, que futuramente será ofertado em uma empresa. A empresa

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será selecionada e no futuro, uma ementa será apresentada ao CEP para a aplicação do treinamento citado. Portanto, nesse momento solicita-se a apreciação para a realização do debate e das entrevistas.

O recrutamento dos respondentes será realizado através da rede de contatos do responsável pela pesquisa, do professor orientador, do professor co-orientador e também por meio de redes sociais digitais voltadas a atuação profissional.

Os participantes para o debate serão convidados via email e receberão o TCLE on line. Depois estabelece-se uma data para o debate que deve durar 02hrs. O mesmo procedimento para os participantes da entrevista. O pesquisador anexou ao projeto o questionário para o DEBATE e ENTREVISTA.

Considerações sobre os Termos de apresentação obrigatória:

O pesquisador apresentou os documentos exigidos pela Resolução 466/12, a saber:

- Folha de Rosto de acordo
- Cronograma de acordo
- Critérios de inclusão e exclusão de acordo
- TCLEs de acordo
- Financiamento CNPQ conforme descrição
- Roteiro de entrevistas de acordo

Recomendações:

A Comissão Nacional de Ética em Pesquisa (Conep), do Conselho Nacional de Saúde (CNS) orienta a adoção das diretrizes do Ministério da Saúde (MS) decorrentes da pandemia causada pelo Coronavírus SARS-CoV-2 (Covid-19), com o objetivo de minimizar os potenciais riscos à saúde e a integridade dos participantes de pesquisas e pesquisadores.

De acordo com carta circular da CONEP intitulada “ORIENTAÇÕES PARA CONDUÇÃO DE PESQUISAS E ATIVIDADE DOS CEP DURANTE A PANDEMIA PROVOCADA PELO CORONAVÍRUS SARS-COV-2 (COVID-19)” publicada em 09/05/2020, referente ao item II. “Orientações para Pesquisadores”:

- Aconselha-se a adoção de medidas para a prevenção e gerenciamento de todas as atividades de pesquisa, garantindo-se as ações primordiais à saúde, minimizando prejuízos e potenciais riscos, além de prover cuidado e preservar a integridade e assistência dos participantes e da equipe de pesquisa.
- Em observância às dificuldades operacionais decorrentes de todas as medidas impostas pela

pandemia do SARS-CoV-2 (COVID- 19), é necessário zelar pelo melhor interesse do participante da pesquisa, mantendo-o informado sobre as modificações do protocolo de pesquisa que possam afetá-lo, principalmente se houver ajuste na condução do estudo, cronograma ou plano de trabalho.
- Caso sejam necessários a suspensão, interrupção ou o cancelamento da pesquisa, em decorrência dos riscos imprevisíveis aos participantes da pesquisa, por causas diretas ou indiretas, caberá aos investigadores a submissão de notificação para apreciação do Sistema CEP/Conep.
- Nos casos de ensaios clínicos, é permitida, excepcionalmente, a tramitação de emendas concomitantes à implementação de modificações/alterações no protocolo de pesquisa, visando à segurança do participante da pesquisa, assim como dos demais envolvidos no contexto da pesquisa, evitando-se, ainda, quando aplicável, a interrupção no tratamento dos participantes da pesquisa. Eventualmente, na necessidade de modificar o Termo de Consentimento Livre e Esclarecido (TCLE), o pesquisador deverá proceder com o novo consentimento, o mais breve possível.

Conclusões ou Pendências e Lista de Inadequações:

Informamos ao pesquisador que de acordo coma a Resolução 466/12, a eticidade da pesquisa implica em respeito ao participante da pesquisa em sua dignidade, autonomia e garantias de plena liberdade em participar ou recusar a participação em qualquer fase da pesquisa. O participante deverá ser abordado uma única vez, e caso não concorde em participar da pesquisa, e-mails e convites online não serão mais disparados para estes participantes.

projeto aprovado

Considerações Finais a critério do CEP:

- O participante da pesquisa deve receber uma via do Termo de Consentimento Livre e Esclarecido, na íntegra, por ele assinado (quando aplicável).

- O participante da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (quando aplicável).

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Continuação do Parecer: 4.111.235

- O pesquisador deve desenvolver a pesquisa conforme delineada no protocolo aprovado. Se o pesquisador considerar a descontinuação do estudo, esta deve ser justificada e somente ser realizada após análise das razões da descontinuidade pelo CEP que o aprovou. O pesquisador deve aguardar o parecer do CEP quanto à descontinuação, exceto quando perceber risco ou dano não previsto ao participante ou quando constatar a superioridade de uma estratégia diagnóstica ou terapêutica oferecida a um dos grupos da pesquisa, isto é, somente em caso de necessidade de ação imediata com intuito de proteger os participantes.

- O CEP deve ser informado de todos os efeitos adversos ou fatos relevantes que alterem o curso normal do estudo. É papel do pesquisador assegurar medidas imediatas adequadas frente a evento adverso grave ocorrido (mesmo que tenha sido em outro centro) e enviar notificação ao CEP e à Agência Nacional de Vigilância Sanitária – ANVISA – junto com seu posicionamento.

- Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas e aguardando a aprovação do CEP para continuidade da pesquisa. Em caso de projetos do Grupo I ou II apresentados anteriormente à ANVISA, o pesquisador ou patrocinador deve enviá-las também à mesma, junto com o parecer aprovatório do CEP, para serem juntadas ao protocolo inicial.

- Relatórios parciais e final devem ser apresentados ao CEP, inicialmente seis meses após a data deste parecer de aprovação e ao término do estudo.

-Lembramos que segundo a Resolução 466/2012 , item XI.2 letra e, “cabe ao pesquisador apresentar dados solicitados pelo CEP ou pela CONEP a qualquer momento”.

-O pesquisador deve manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período de 5 anos após o término da pesquisa.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

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Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1573985.pdf	10/06/2020 12:59:38		Aceito
Outros	Carteira_Unicamp.pdf	10/06/2020 12:56:47	Gustavo Tietz Cazeri	Aceito
Outros	Formulario2_ENTREVISTAS.pdf	10/06/2020 12:55:34	Gustavo Tietz Cazeri	Aceito
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TCLE / Termos de Assentimento / Justificativa de Ausência	Dois_TCLEs_juntos.pdf	10/06/2020 11:58:26	Gustavo Tietz Cazeri	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_CEP_10_06_2020.pdf	10/06/2020 11:58:03	Gustavo Tietz Cazeri	Aceito
Folha de Rosto	Folha_de_Rosto.pdf	10/06/2020 11:38:21	Gustavo Tietz Cazeri	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

CAMPINAS, 25 de Junho de 2020

Assinado por:
Renata Maria dos Santos Celeghini
(Coordenador(a))

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2022-04-08

How to Cite

Cazeri, G. T., Santa-Eulália, L. A. de, Serafim, M. P., & Anholon, R. (2022). Training for Industry 4.0: a systematic literature review and directions for future research. *Brazilian Journal of Operations & Production Management*, *19*(3), 1–19. https://doi.org/10.14488/BJOPM.2022.007

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