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DIGITAL TRANSFORMATION IN MANUFACTURING SMEs: A BIBLIOMETRIC ANALYSIS USING VOSviewer

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Abstract. The present paper aims to identify the main trends and gaps in the digitalization of manufacturing SMEs. The most significant literature on this emergent theme was gathered through a criterion search, resulting in discovering 4060 related documents. To narrow this considerable number of documents, a bibliometric analysis was performed. A database was exported from Clarivates' Web of Science for clusters analysis in VOSviewer's software. Afterward, it was possible to identify the top authors and documents. Four trends were identified: one Asian, headed by China; another Anglo-Saxon, led by the USA; and two European trends, run by Italy and Germany. Furthermore, were identified two research gaps: (1) The development of pro-environmental technology and (2) digital readiness models for manufacturing SMEs.

Keywords: digital transformation, Industry 4.0, manufacturing, bibliometric analysis, VOSviewer.

JEL Classification: M10, M15, O30, O32.

Introduction

Industry 4.0 (I4.0) or Industrie 4.0, initially debuted at the 2011 Hannover Fair, ended to be announced as the German strategic initiative to push their industries to be pioneers in revolutionising the manufacturing sector (Xu et al., 2018).

I4.0 makes use of 9 specific, ground-breaking, ongoing development, booming technologies: big data and analytics, autonomous robots, simulation, horizontal and vertical system integration, the industrial internet of things, cybersecurity, the cloud, additive manufacturing, and augmented reality (Ruessmann et al., 2015).

The fourth industrial revolution is an ongoing amalgamation of new technologies pushing the boundaries of the world´s manufacturing capability, so our nations' competitiveness is at stake. It is questioning the survival of our industries and organizations. It is changing our lives as we know them. The opening of new possibilities, more practical ways of doing things are also changing our societies. Its advent is ending jobs and creating new ones. New resources with new skills are needed (Bag et al., 2021). It is hard to say what the future will be, but we know that I4.0 is happening now and brings powerful technologies. But how to take advantage of it? How to benefit from it, pushing us further, and not be shattered by it. The real benefits of I4.0 are not written in stone, so it is no surprise that it consists of an essential topic for researchers (Bag et al., 2021).

The present paper addresses the theme of digital transformation in manufacturing Small and Medium-Sized Enterprises (SMEs) to respond to 3 Research Questions (RQ):

– RQ1: What are the quality research documents to systematically review the topic of digital transformation in manufacturing SMEs?
– RQ2: What are the main research trends?
– RQ3: What are the main research gaps?

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After a first attempt at getting to know the quality research documents on this theme, we came across a significant amount of data. Exactly 4,060 documents met our search. A considerable number of papers were presented at conferences. Among the resulting documents, few come from late 2005, and more than 63% come from 2017. Figure 1 shows the exponential growth in this research area for the past five years. Two thousand twenty-one totals almost the same number of documents produced as the number of citations. These figures allow us to state that this is an emergent research area. Because of this, to better address the issue of selecting the most important documents to analyse, generating state-of-the-art on the matter, a specific methodology was applied.

A systematic mapping review (Haddaway & Macura, 2018), also known as a bibliometric analysis, helps the researcher identify trends and gaps in a particular set of research documents referred to a specific knowledge area (Muhuri et al., 2019). Haddaway and Macura (2018) consider this method capable of mapping out and categorising existing literature on a broad subject to commission primary research by identifying gaps in the literature or pursuing further research through cluster analysis. The authors also state that this method is "*accepted as the …' gold standard' form of evidence synthesis*" (Haddaway & Macura, 2018, p. Supplementary table 1).

Nowadays, bibliometric analysis can be better performed using software to construct and view bibliometric maps (van Eck & Waltman, 2010).

The researchers have chosen the VOSviewer software (van Eck & Waltman, 2022) because it is open-source software, in continuous development by the mentioned authors (it is now in its 39th iteration since it was first launched in 2009), and because of its ability to display bibliometric maps with accuracy and in different visual possibilities and resolutions.

To better use the databases exported from Clarivate's Web of Science, they had to be refined by a process provided by VOSviewer and still needed to use another software. In this case, Notepad++ (Ho, 2022). The latter was used to guarantee no duplicates or other errors that may generate biased results in VOSviewer. The possibilities in visualization opened by VOSviewer software and the cluster analysis give insights capable of drawing predictions, trends, and research gaps.

The contribution made from this research consists of the following:

- A bibliometric analysis on the emergent theme of industry 4.0 in the field of manufacturing SMEs;
- Showed proof of the exponential growth of the emergent theme of I4.0 in the field of manufacturing SMEs;
- An analysis of popular metrics for this specific field: top-cited documents authors; top-cited documents; top-productive countries; top-productive institutions; and most common author keywords;
- A cluster analysis using the outputs given by the VOSviewer software;
- Discussion over the conclusions and future research suggestions makes it possible to appoint trends and research gaps.

This paper is organised into five sections; after the introduction, the second section aims to demonstrate the methodology applied in this research. After that, the bibliometric maps are viewed and analysed. In the fourth section, a cluster analysis is performed. Top contributors, authors, organisations, and countries are also identified. The final section presents conclusions and future work.

1. Research methodology

Bibliometric intel was retrieved from Clarivate's Web of Science repository in text file databases.

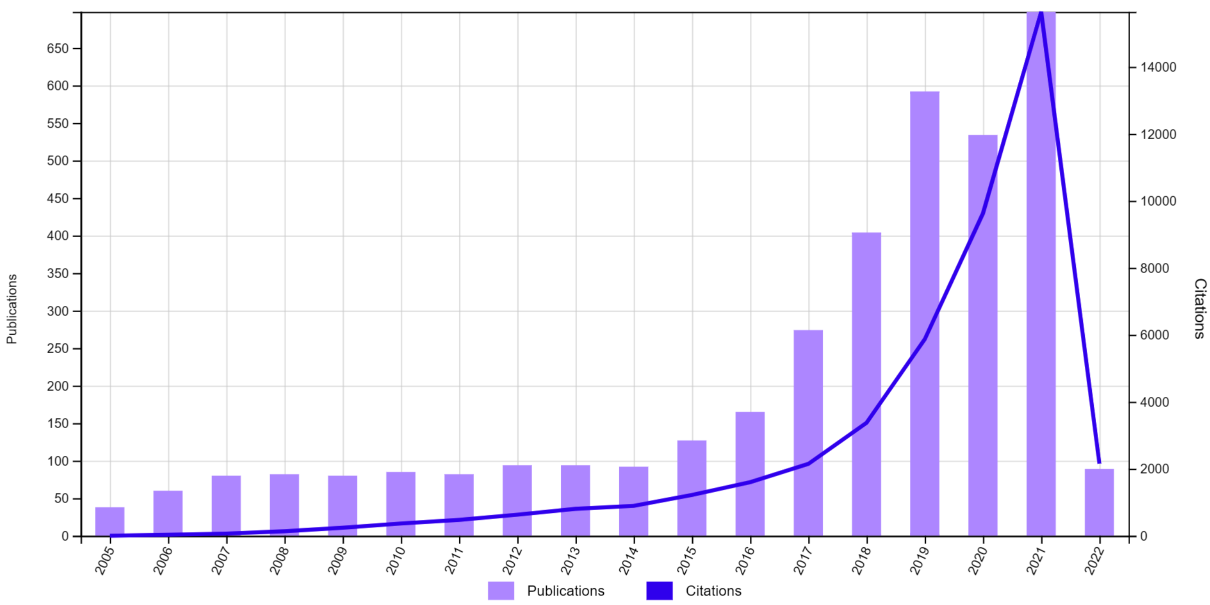


Figure 1. Search results times cited and publications over time (source: Web of Science, n.d.)

The search script is presented as follows:

1. Date: 2022/02/26;
2. Query link: https://www.webofscience.com/wos/woscc/summary/2aa51d66-8d89-4e4a-8b76-2f401d-d7864b-260c114b/relevance/1
3. Results: 4060 documents;
4. Terms:
   "im" or "intelligent manufacturing" or "digital trans*" or "digit*" or "I4.0" or "industr* 4.0" or "4th industrial revolution" or "fourth industrial revolution" or "smart factor*" or "smart manufacturing enterpris*" (All Fields)
   AND
   "SME*" or "manufactur*" (All Fields)
   AND
   "readiness" or "maturity" or "capabilit*" (All Fields)
5. Document types: Review Articles or Articles or Proceedings Papers;
6. Languages: English;
7. NOT: Presented in appendix 1.

The databases were further refined using the "thesaurus" file function provided by the VOSviewer. To acquire the refinement, it was necessary to use another software, Notepad ++. The refinement consists of correcting duplicates and potential errors from the database itself. Not doing so could infect the outcome results, making the conclusions irrelevant.

Without further due, the following section addresses the bibliometric analysis.

2. Bibliometric data and mapping

Top-cited documents authors; top-cited documents; top-productive countries; top-productive institutions; and top-common keywords are here scrutinized.

The top-10 cited documents authors are as follows (Web of Science H index of submission author and biggest scorer):

1. Rai, Arun (H:45); Patnayakuni, Ravi (H:11); Seth, Nainika
2. Lee, Jay (H:33); Kao, Hung-An (H:7); Yang, Shanhu
3. Frank, Alejandro German (H:19); Dalenogare, Lucas Santos; Ayala, Nestor Fabian (H:8)
4. Leigh, Simon J. (H:10); Bradley, Robert J.; Purssell, Christopher P.; Billson, Duncan R.; Hutchins, David A. (H:41)
5. Schumacher, Andreas (H:13); Erol, Selim; Sihn, Wilfried (H:18)
6. Ghobakhloo, Morteza (H:15)
7. Leitao, P (H:26); Restivo, F (H:10)
8. Li, Ling (H:32)
9. Brunswicker, Sabine (H:9); Vanhaverbeke, Wim (H:29)
10. Tay, Yi Wei Daniel (H:9); Panda, Biranchi; Paul, Suvash Chandra; Mohamed, Nisar Ahamed Noor; Tan, Ming Jen; Leong, Kah Fai (H:45)

The top-10 cited documents and sources are as follows (Journal Impact Factor & correspondent Quartile):

1. Firm performance impacts of digitally enabled supply chain integration capabilities (7.198 & Q1) (Rai et al., 2006);
2. Service innovation and smart analytics for Industry 4.0 and big data environment (Lee et al., 2014);
3. Industry 4.0 technologies: Implementation patterns in manufacturing companies (7.885 & Q1) (Frank et al., 2019);
4. A Simple, Low-Cost Conductive Composite Material for 3D Printing of Electronic Sensors (3.24 & Q2) (Leigh et al., 2012);
5. A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises (Schumacher et al., 2016);
6. The future of manufacturing industry: a strategic roadmap toward Industry 4.0 (7.547 & Q1) (Ghobakhloo, 2018);
7. ADACOR: A holonic architecture for agile and adaptive manufacturing control (7.635 & Q1) (Leitão & Restivo, 2006);
8. China's manufacturing locus in 2025: With a comparison of Made-in-China 2025 and Industry 4.0 (8.593 & Q1) (Li, 2018);
9. Open Innovation in Small and Medium-Sized Enterprises (SMEs): External Knowledge Sourcing Strategies and Internal Organizational Facilitators (4.544 & Q2) (Brunswicker & Vanhaverbeke, 2015)
10. 3D printing trends in building and construction industry: a review (8.092 & Q1) (Tay et al., 2017).

Seven documents weren't included for being out of scope, besides having scored higher than some of the listed ones (Barua et al., 2004; Cressler, 1998; El et al., 2003; Hon et al., 2008; Pan et al., 2011; Sutton et al., 2000; Wu et al., 2014)

The top-10 productive countries are as follows, in terms of produced documents: 1. USA: 891; 2. China: 655; 3. England: 383; 4. Germany: 369; 5. Italy: 253; 6. India: 149; 7. Spain: 133; 8. France: 130; 9. Taiwan: 129; 10 Finland: 112.

The top-ten most common keywords, in terms of occurrences:

1. I4.0: 572;
2. Digital transformation: 241;
3. Additive manufacturing: 202;
4. SMEs: 184;
5. Smart factories: 178;
6. IoT: 113;
7. Cyber-physical production systems: 92;
8. Manufacturing: 87;
9. Digital twin: 80;
10. Maturity model: 69.

The bibliometric mapping provided by VOSviewer produced two visualizations. One regarding a co-occurrence analysis with author keywords as a unit in network visualization and the other in overlay visualization. The first organized itself into 8 clusters (following presented with all the keywords disclosed in each cluster), with items collected by occurrences as follows:

– Cluster 1 (RED) – 584 total occurrences: top 5 are 'artificial intelligence, 'automation', 'neural networks', 'multi-agent systems', and 'intelligent manufacturing systems'.
– Cluster 2 (GREEN) – 1076 total occurrences: top 5 are 'digital transformation', 'small medium enterprise', 'sustainability', 'big data', and 'case study'.
– Cluster 3 (NAVY) – 799 total occurrences: top 5 are 'iot', 'cyber-physical production systems', digital twin', 'cloud manufacturing', and 'optimization.
– Cluster 4 (YELLOW) – 991 total occurrences: top 5 are 'industry 4.0', 'maturity model', 'augmented reality', 'virtual reality', and 'capabilities'.
– Cluster 5 (PURPLE) – 577 total occurrences: top 5 are 'smart factories', 'machine learning', 'digital manufacturing system', 'simulation', and 'genetic algorithms'.
– Cluster 6 (BLUE) – 482 total occurrences: top 5 are 'additive manufacturing', 'digital image correlation', 'rapid prototyping', 'digital light processing', and 'image processing'.
– Cluster 7 (ORANGE) – 393 total occurrences: top 5 are 'manufacturing', 'servitization', 'business model', 'product-service systems', and 'manufacturing industries'.
– Cluster 8 (BROWN) – 38 total occurrences: top 5 are 'computer-aided design', 'digital maturity', 'manufacturing companies', 'barriers', and 'information management'.

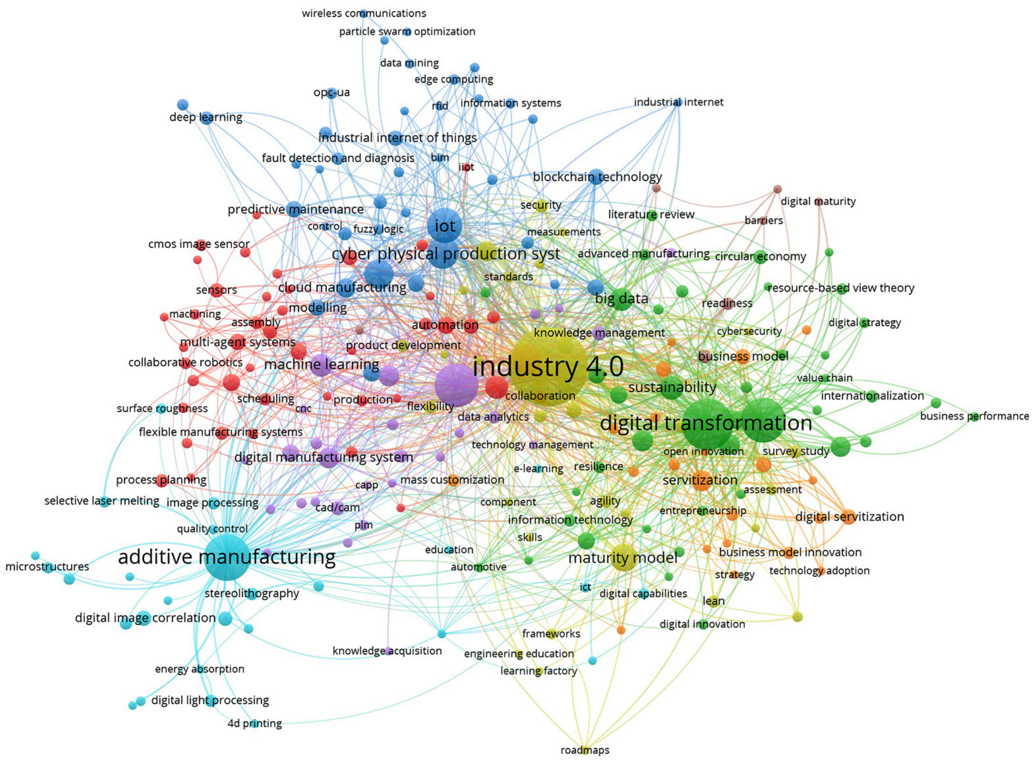
It is essential to explain how a map in network visualization is developed (Figure 2). The items that are previously mentioned are represented by their label and by a circle. The size of the circle is determined by the number of occurrences, meaning that more occurrences originate from a bigger circle.

As previously demonstrated in the table, clusters show independent colours. So, all the items match the colour of the cluster they belong to. Some items don't display their names because the map wouldn't be visually appealing, understandable, and meaningful if it did.

The constant labels overlapping would show a soap of letters and not a bibliometric map. The lines between the items represent links. The distance between two items indicates how much they are related to each other. The closely they appear, the more connected they are. The more apart from each other means, the less related they are. Also, the thickness of a line representing a link is also representative. The thicker the line, the stronger the connection between them. Figure 3 shows the same map, items, and network but with a different gradient of colours. It is called overlay visualization. Items that are shown in a more yellowish colour are more recent as opposed to those that are shown in a more bluish colour.

3. Results and discussion

From a subjective analysis, we can relabel the clusters according to the items or terms they aggregate and give them their reason to be.



VOSviewer

Figure 2. Map in network visualization – Co-occurrence with author keywords as a unit (source: VOSviewer, n.d.)

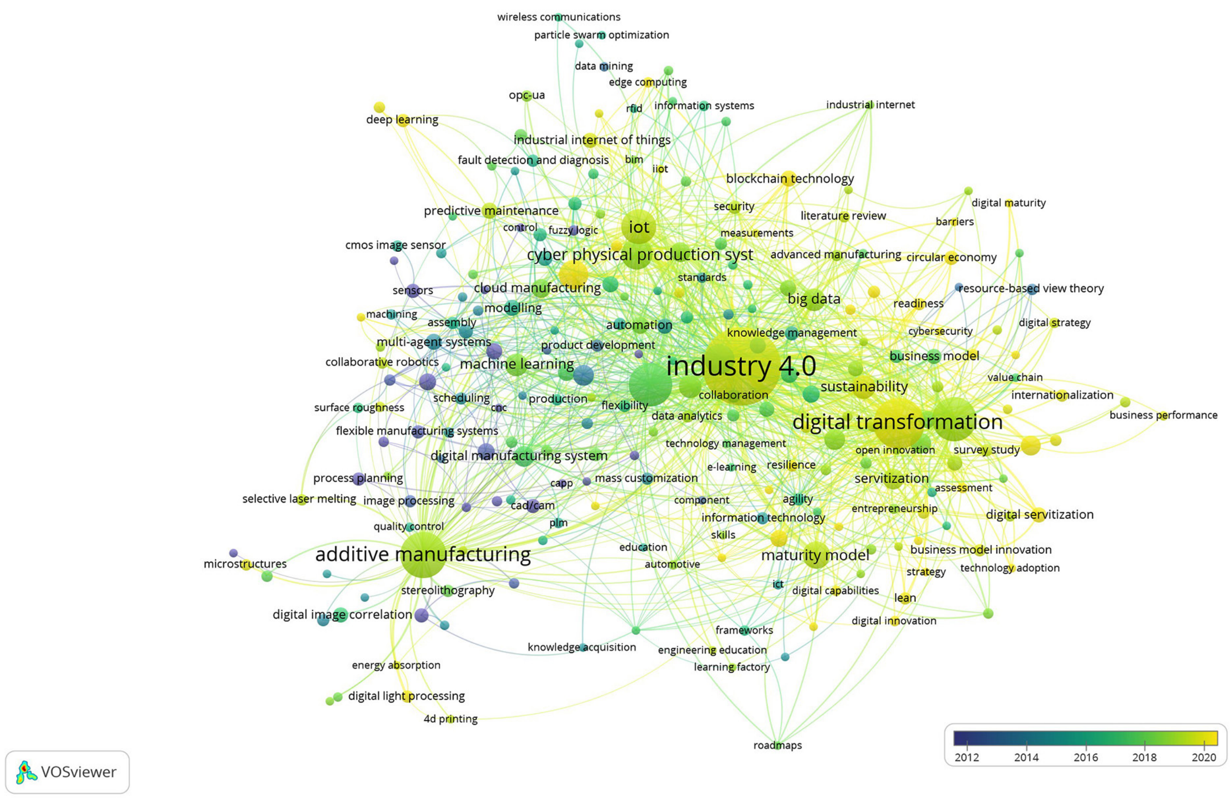


Figure 3. Map in overlay visualization – Co-occurrence with author keywords as a unit (source: VOSviewer, n.d.)

So, this study proposes the following new clusters labels:

- Cluster 1 – AI;
- Cluster 2 – Digital transformation in manufacturing;
- Cluster 3 – The internet of everything;
- Cluster 4 – Industry 4.0;
- Cluster 5 – Smart factories;
- Cluster 6 – Additive manufacturing;
- Cluster 7 – Business development of I4.0;
- Cluster 8 – I4.0 challenges.

According to the total occurrences per cluster, we can say that the most mature are clusters 2 and 4. Cluster 7 shows minor occurrences, although the terms are significant enough to be put on a distinct cluster.

The overlay visualization analysis shows that critical concepts such as I4.0 and Digital Transformation continue to be widely addressed. Simultaneously, there is a transition from the manufacturing domains found on the items on the left side of the map towards business aspects, such as digital strategy, innovation, performance, and digital maturity, items found on the right side of the map.

The overlay analysis corroborates the assumption made by considering cluster 8 as the challenging one because it revolves around digital maturity.

Although bibliometric mapping points us to these trends and gaps, bibliometric data showed some different yet significant aspects.

The bibliometric data shows that most of the quality knowledge produced in this research area is divided into four currents: Asian, led by China; Anglo-Saxon, led by the USA; and two European currents. Germany leads one, and Italy leads the other.

We can also conclude from the top-cited documents that the scope of our search is not being targeted for research and has not been in the past.

The development of pro-environmental technologies was not present. There are remarks on sustainability, but no quality research was found in this database.

Conclusions and future work

We have identified that cluster 2 – Digital Transformation in Manufacturing, and cluster 4 – Industry 4.0, are the significant areas targeted for research. It is also noticeable that since 2018 cluster 6 – Additive manufacturing has not been targeted for research in favour of cluster 2.

So, because of the present bibliometric analysis, and considering the results and discussion made in the previous section, to answer RQ1, the authors can conclude that more needs to be done to identify quality work in the adoption of I4.0 technologies by SMEs. Even so, significant contributions were here given.

Regarding RQ2, the combined analysis of clusters 2 and 4 pointed to fruitful research topics, such as developing methods and tools to manage these technologies better in more strategical and innovative ways. These conclusions may direct the commission of further research.

As for RQ3, because of the analysis made to cluster 8 – I4.0 challenges, the authors propose a simultaneous integrated view of how all these concepts could be addressed towards ensuring a fruitful implementation of I4.0 in SMEs, namely by establishing key milestones and pointing alternative paths towards increasing the digital maturity and companies' readiness level to be fully prepared to future challenges. On the other hand, these conclusions may direct us to conduct primary research.

Disclosure statement

The Authors state that they have not any competing financial, professional, or personal interests from other parties.

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APPENDIX 1

NOT:
Web of Science Categories: Zoology or Water Resources or Veterinary Sciences or Urban Studies or Transplantation or Toxicology or Substance Abuse or Social Sciences Mathematical Methods or Respiratory System or Reproductive Biology or Religion or Rehabilitation or Psychology Educational or Political Science or Physics Atomic Molecular Chemical or Orthopedics or Obstetrics Gynecology or Neuroimaging or Microbiology or Mathematics or Limnology or Immunology or Geology or Gastroenterology Hepatology or Fisheries or Evolutionary Biology or Entomology or Dermatology or Chemistry Medicinal or Art or Area Studies or Anthropology or Anatomy Morphology or Allergy or Agricultural Economics Policy or Statistics Probability or Sport Sciences or Soil Science or Sociology or Quantum Science Technology or Psychology Experimental or Psychology or Plant Sciences or Peripheral Vascular Disease or Mining Mineral Processing or Mineralogy or Marine Freshwater Biology or Humanities Multidisciplinary or Genetics Heredity or Forestry or Anesthesiology or Agronomy or Agricultural Engineering or Pathology or Ophthalmology or Oncology or Nutrition Dietetics or Medical Laboratory Technology or Meteorology Atmospheric Sciences or Law or International Relations or Crystallography or Chemistry Organic or Chemistry Inorganic Nuclear or Cell Biology or Agriculture Multidisciplinary or Surgery or Physics Mathematical or Neurosciences or Medicine General Internal or Geochemistry Geophysics or Biophysics or Cardiac Cardiovascular Systems or Public Environmental Occupational Health or Psychology Multidisciplinary or Psychology Applied or Medicine Research Experimental or Health Care Sciences Services or Biochemistry Molecular Biology or Behavioral Sciences or Spectroscopy or Physics Fluids Plasmas or Microscopy or Mathematical Computational Biology or Geography Physical or Geography or Thermodynamics or Physics Multidisciplinary or Chemistry Applied or Acoustics or Physics Nuclear or Oceanography or Dentistry Oral Surgery Medicine or Biochemical Research Methods or Materials Science Ceramics or Geosciences Multidisciplinary or Physics Particles Fields or Ergonomics or Biotechnology Applied Microbiology or Pharmacology Pharmacy or Architecture or Mathematics Applied or Astronomy Astrophysics