A Bibliometric Content Analysis of Do-it-Yourself (DIY) Science: Where to From Here for Management Research?

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A BIBLIOMETRIC CONTENT ANALYSIS OF DO-IT-YOURSELF (DIY) SCIENCE: WHERE TO FROM HERE FOR MANAGEMENT RESEARCH?

ABSTRACT

Do-it-yourself (DIY) science research is currently in an expansion phase both in terms of its depth (with an increasing number of papers published each year) and its scope (with the core ideas being linked to an increasing number of constructs). To develop a more holistic appreciation of how the field has developed and to identify potential avenues of future research we undertake a bibliometric content analysis of the DIY science literature post 1980. We find four major clusters pertaining to education, culture, the operationalising of DIY science (including commercialisation) and technology-related issues. We review each of these clusters and the main themes contained within the cluster, including highlighting possible research questions that align to these key themes. We find the field to be highly dispersed theoretically on the basis of the bibliometric content analysis. In considering a range of sample papers in each thematic cluster, we identify a range of potential research topics going forward. Identifying the key thematic foci of DIY science research to date provides the researchers within the field the opportunity to clearly locate their work within a highly diverse literature and to build new research trajectories around core concepts.

Keywords: DIY science, bibliometric content analysis, institutional science

INTRODUCTION

Engaging in science and expanding scientific knowledge has, for much of history, been the domain of interested individuals rather than corporate entities. Interest in science grew as society progressed through Galilean and Newtonian times to the Victorian era that brought about the movement of 'gentleman scientists' (Barton, 2003; Gallopin et al, 2001). Science could be of interest to many in the same way as a hobby such as gardening or philately (Waller, 2001). In fact, the distinction between 'professionals' and 'amateurs' was not even a consideration until 1878 when William Spottiswoode, occupying the highest position in British science as President of the British Association, also ran for President of the Royal Society of London against Stokes (a Professor of Mathematics at Cambridge) and self-identified as an amateur (Barton, 2003). Spottiswoode was successful and 'gentleman scientists' continued to be an important part of the scientific development landscape for some time.

This changed with the growth of the industrial complex through two World Wars and in the decades that followed with the advent of multinationals that relied heavily upon R&D driven innovation. Government funding to large industrial organisations for war-related goods (and often associated research) grew over the 20th Century across two World Wars and particularly during the Cold War in the latter part of the century. This, coupled with significant growth in the university sector, saw active participation in scientific endeavours almost exclusively shift towards 'professionals'. By the latter half of the 20th Century, companies such as AT&T, Du Pont, IBM and Xerox, along with university research centres, ended the period of the gentleman scientist and instead saw the focus shift to a more corporate model, often built around scale (Arora et al., 2017).

More recently, the growth of do-it-yourself (DIY) science may reflect both a reduction in scientific research by large corporations (Arora et al., 2017) and a simultaneous growth in DIY/citizen science and DIY laboratories (Sarpong et al., 2020) that harks back to the notion of the gentleman scientist. In this way scientists, members of the public who are interested in science and people who would otherwise be excluded from science, may become involved in the world and practice of science in a way that was not possible for most people through the latter part of the 20th Century.

DIY science has emerged as an important phenomenon and allows for the democratisation of science by challenging the corporate model and allowing interested individuals to engage in scientific endeavours through a variety of pathways from community laboratories to tinkering in garages. At a practical level, the growth of DIY science is facilitated by the availability of scientific information including open access material, equipment from 3D printers to computer numerical control (CNC) machining tools becoming increasingly affordable, and the capacity to engage in various online forums with like-minded people (Million-Perez, 2016). By expanding the opportunities for people to engage in science outside of corporate and university/research institution settings, there is the potential for increased economic and social benefits to flow to both participants and regions supporting DIY science activities (Fox, 2014; Meissner et al., 2020; You et al, 2020).

Recent studies have underscored the surging trend of DIY labs/biolabs, fab labs, makerspaces and hackerspaces being established around the world (You et al., 2020); coupled with a general recognition of the growing importance of DIY science in various fields (Sarpong et al., 2019; Meissner et al., 2020; Wulandhari et al., 2020). However, the field is very heterogeneous. While there is a growing interest in the DIY phenomena, there are divergent conceptualisations of what related DIY concepts encompass and how they operate – warranting an effort to better understand this seemingly disparate set of activities. For instance, the way that DIY laboratory activities are discussed in terms of the characteristics of such laboratories and their challenges, is very different to researchers looking at the DIY laboratory phenomena through a makerspace lens. While there is a commonality in that the innovations occur outside of a formal corporate structure or traditional research institution, a field cannot be defined by what it is not. Rather, through a bibliometric content analysis we seek to answer the question of 'what are the key conceptual themes in the DIY science (and related topics) literature?'. This may provide insight into the alignment of the research and the commonalities of this work, as well as suggesting future research paths that may warrant further investigation.

Through greater clarity around the different themes that presently exist in DIY science research and how they may (or may not) integrate, we believe that future research will be able to more clearly position itself within larger discourses that are often featured and thus move beyond definitional issues and descriptions of observed activities. Further, by reviewing a selection of papers that fall into each theme, we may proffer fertile avenues for further impactful research and integrate more successfully with issues from other fields which have at times been considered in the context of DIY science such as science, technology and innovation (STI) policy at the macro-level, and firm-level considerations in respect of building effective business models and collaborative structures.

BACKGROUND

To determine which terms to include in the bibliometric content analysis, we initially consider what is DIY science and what other concepts are highly related or overlap theoretically. DIY science refers to the phenomenon whereby private and community-based initiatives are undertaken using scientific approaches, in addition to other forms of inquiry such as hacking, with the aim of finding solutions for community-based concerns and techno-scientific challenges (You et al., 2020). The associated activities of DIY science are more participatory and transdisciplinary than those found in the dominant institutional model, and the actors involved range from professional scientists, amateurs, hobbyists, to non-specialists (Griffiths, 2014). Although subtly (or in some cases, considerably) different, DIY science is often used synonymously with other concepts such as citizen science, civic science, and open science (You et al., 2020) and may operate out of a variety of spaces including DIY laboratories, fab labs, DIYbio, hackerspaces, makerspaces, citizen laboratories, as well as home workshops, garages, basements and other accessible locations (Meissner et al., 2020; Grushkin et al., 2013).

All of these concepts highlight the incorporation of a broader base of people in scientific endeavours aligning with the notion of democratising science. However, the focus of citizen-related versus DIY notions (which include hacker- and makerspaces) differ considerably. DIY-related terminology tends to highlight the non-institutional nature of scientific inquiry and the accessibility to a broad range of individuals that underpin the scientific work being undertaken. This work may then be undertaken in relatively formalised facilities or in a variety of non-traditional research spaces. A variety of DIY science spaces have been purposely created through public policy initiatives to provide independent community-based science research hubs (Hecker et al., 2018) and may be funded by both corporate sponsorship or government funds. Some of these more formalised community-based laboratories align with particular groups such as The Fab Foundation (with nearly 2000 fab labs in place), DIYbio (108 groups) and hackerspaces (over 2000 either operational or in development) (You et al., 2020). Less formalised spaces such as garages, workshops, basements, libraries and other public spaces may also support DIY science activities (Nascimento et al., 2014).

Across these different DIY science spaces, we tend to find different models of operations and different scientific foci (Fritzsche, 2020; You et al., 2020). For instance, makerspaces in particular (and some fab labs) tend to employ low-cost technologies in all stages of the product development process and operate as spaces where hardware is used for alteration and repairs or for fabrication of new products built around repurposing existing components (Fritzsche, 2020). Fab labs and techshops have a specific focus on digital fabrication, while hackerspaces tend to be more oriented towards the leveraging of computers, programming, technology and electronics (Cavalcanti, 2013; You et al., 2020). DIY biolabs are focused on biological investigation (Sarpong et al., 2020). Finally, DIY laboratories tends to be something of an umbrella phrase that captures the notion of scientific work being undertaken outside of an institutionalised model. It covers the social and physical spaces for technology enthusiasts and entrepreneurs to explore their ideas and thrive (You et al., 2020), irrespective of the science base of the work being undertaken. It can include the more structured labs such as La Paillasse or BiologiGaragen in Copenhagen, as well as single enthusiasts operating out of their basements, home workshops, garages and kitchens (Galvin et al., 2020; Sarpong et al., 2020).

In comparison, citizen science or civic science, involves the public aspects of scientific research projects usually led by research institutions such as universities (Nascimento et al., 2014; Eitzel et al., 2017). The participation of citizen scientists in research projects do not involve the framing of the questions or deciding the approaches to deploy, but tend to be centred on data collection, resource provision and analysis (Sarpong et al., 2020).

DIY science versus institutional models

As part of defining terms, an implicit focus of DIY science has been to discuss those dimensions that differentiate it from institutional science. These points of differentiation are numerous but consider who tends to be involved, what these people pursue in terms of projects, why they engage with the DIY model and how they engage, especially in terms of funding.

People attracted to DIY science tend to have some formal qualifications in science with one study considering those involved in DIY biolabs reporting that 46% of participants held a postgraduate degree and a further 37% had completed an undergraduate qualification (Grushkin et al., 2013). Lhoste (2020), as both an active participant in some DIY spaces and a researcher, suggests that the movement is strongly associated with the counterculture philosophy that emerged in the 1970s. Participants are motivated by the desire to meet people with similar interests and share ideas and learn from each other (Davies, 2018). These spaces are more associated with a 'hacking culture' and activities rely on emancipatory narrative and extend beyond consumption to production (Fox et al., 2015; Fritzsche; 2020). The focus of much of the work is on practical problems that need resolution, but are not considered by corporate operations to be of sufficient importance that they will invest in the necessary research and product development. As such, actors in these spaces tend to employ different approaches to engineering, design and innovation (Richardson et al., 2013). However, depending on the sensitivity of the research project, participants or visitors to these labs may be restricted from direct involvement in the alteration or fabrication of technical architectures and algorithms as evidenced by Fritzsche (2020) in an IT security open lab project in Germany. In makerspaces and fab labs, the sovereignty of actors is observed only through the alteration and fabrication of artifacts, while in other open laboratories sovereignty is established by users through a wide scope of agenda-setting and sense making activities and behaviours (Fritzsche, 2020).

Unlike traditional corporate research environments, or those found in research institutions where participation is restricted, the openness in the DIY science settings provides actors with freedom to adopt their own approaches and take liberties in testing their ideas in ways which could be unthinkable in the traditional research institutions and industry (Fritzsche, 2020; Sarpong & Raval, 2020). Moreover, in traditional institutions there tend to be some repetition of tasks undertaken with a determined output in mind (Willoughby & Galvin, 2005; Fritzsche, 2020). Due to the freedom that is available to DIY lab participants, they are able to pursue alternative paths that may not make sense to larger corporate players such as the craft beer examples in Ng, Arndt and Huang (2020) or the 'Nightscout Project' that explored adapting a glucose monitoring system for diabetes (Lee et al., 2016). DIY labs are also used for translating innovative products in one industry into another relatively unrelated industry via exaptive innovation (eg Galvin, 1999; Galvin et al., 2020). Overall, outsiders to the institutional science model have been able to leverage DIY science principles as both a technical and political basis to manoeuvre around the bureaucracies and restrictions in corporate and traditional research institutions to demonstrate the value and potential of their ideas (Sarpong et al., 2020; Vessal et al., 2020).

Finally, the funding sources of DIY science and labs has often featured as another stream of scholarly inquiry (Nascimento et al., 2014; Ravetz et al., 2015). DIY science and associated laboratories are predominantly funded privately by researchers, though there are extensive examples of funding coming from other sources such as government, university, industry and personal sources – with the funds often being philanthropic in nature (Scheifele & Burkett, 2016; You et al., 2020; Ravetz et al., 2015). DIY science participants struggle to get funding from traditional funding sources such as the Research Councils or funding bodies (Nascimento et al., 2014) and are increasingly relying on crowdfunding (You et al., 2020). However, the relationships between funding sources and outcomes, along with the funding sources used by different approaches to DIY science (for example, DIY biolabs, hackerspaces, etc.) has not been considered due to the relatively fragmented nature of existing research.

A brief review of the who, what, why and how questions suggest that the field is relatively embryonic in nature that is emerging from a multitude of different literature streams and relying upon a diverse nomenclature. Research to date has been fragmented along a number of lines. Most research has considered just one industry or focused upon one type of science. As there are a wide variety of different levels of engagement with science – from highly advanced work around DNA manipulation to tinkering by combining existing mechanical component in different combinations – it is hard to make universal conclusions. Similarly, the spaces used by DIY scientists vary from large advanced laboratories with corporate support to interested individuals working out of a basement. This diversity simply reinforces the fragmented nature of the field. It similarly makes it difficult to develop a clear set of research objectives to drive the field forward. As a starting point to better understand this diversity, we developed our research question: 'what are the key conceptual themes in the DIY science (and related topics) literature?' Whilst this bibliometric content research will not solve the issue of how best to move forward, by looking back at how the field may be thematically organised, we hope that our paper will unpack how the current field is structured and provide a basis for identifying emerging issues and highlight opportunities for future scholarship.

METHODOLOGY

Recent advancements in bibliometrics allow the capture of large volumes of data and parse these through specialist analysis tools to gain a systems view of a particular set of published data (Klarin, 2019; van Eck & Waltman, 2014). To provide a taxonomy of the vastly interdisciplinary topic of DIY science, we employ bibliometric content research methods, which provide a birds-eye view of the field and which allows us to bridge gaps between the variety of disciplines.

There are five main types of bibliometric analyses, which are citation, co-citation, bibliographic coupling, co-author, and content co-occurrence methods (van Eck & Waltman, 2014; Zupic & Čater, 2015). Citation based analyses, citation, co-citation, and bibliographic coupling, are prone to such issues as 'negative citations' (citations refuting previous studies), self-citations, or other issues related to citing. Co-authorship analysis that identifies collaborations between authors is not relevant to the research questions of this study. Thus, we chose to utilise the bibliometric content analysis method due to its use of the actual content in selecting the most frequently used concepts within a body of text, calculating the relationships between these concepts, and thus being able to map these frequently occurring terms based on co-occurrence into a set of research streams.

We also utilised bibliographic coupling methods to identify how the scholarship is clustered where relatedness between publications is based on number of shared references. We then iteratively connected the content analysis results – the extracted frequently occurring terms that are automatically assigned to clusters – to the bibliographically coupled documents representing the entire DIY science scholarship to ensure robustness of findings when comparing and analysing clusters between the two analyses. The assignment of the publications extracted from the bibliographic coupling analysis to the terms allowed us to derive the taxonomy of the scholarship i.e. ‘Clusters of research in DIY science’. Publications are assigned to a cluster when at least half of terms from the topic area of the publication (title, abstract, keywords) belong to a single cluster, and when the topic area contained a minimum of two terms in order to help ensure reliable cluster assignment. As mentioned earlier, we relied on the content analysis instead of the bibliographic coupling analysis as we believe citations in-between publications do not necessarily constitute an objective representation of the field as opposed to the co-occurrence of terms in publications based on their content (Zupic & Čater, 2015). Nevertheless, the bibliographic coupling clusters largely supported the findings of the content analysis, which was confirmatory.

We followed a set of steps to carry out our state-of-the-art bibliometric content review, which structures the current field and offers new perspectives for future research (Grant & Booth, 2009). First, we set out the research question: *what is the state of DIY science scholarship?* It should be noted that while DIY science can occur via a number of set-ups/locations (e.g., DIYbiolabs, fab labs, hackerspaces, etc.), our focus was on the science and did not seek to limit the analysis to any particular sub-set of DIY science. In terms of our study, we sought to analyse a comprehensive and broad range of literature using all publication types including book chapters, editorial material, conference proceedings, research notes, and research letters as a large-sample thematic study of the entire scholarship to provide a more holistic overview of the field (Justeson & Katz, 1995; van Eck & Waltman, 2014). We used the entire Scopus database (Harzing & Alakangas, 2016) with the search queries “*"diy science" or "do it yourself science" or "diy lab*" or "do it yourself lab*" or "citizen lab*" or "community science hubs" or "maker movement" or "diybio" or "do-it-yourself bio*" or "diy bio*" or “fablab” or “fab* *lab" or "makerspace*" or "maker space*'*", which returned 616 publications within the titles, abstracts, and keywords of the original works for the period of 1980 up to 3 December 2020.

The evaluation and mapping of the research were done using an innovative science mapping software, VOSviewer. In the process of generating the mapping reviews, the default settings of the software which generally represent best practices in conducting bibliometric mapping were utilised (van Eck & Waltman, 2010). Based on the entire gathered dataset (616 documents) on the DIY science, the mapping then categorised the content according to the clusters (for a more detailed technical explanation please see van Eck and Waltman, 2010, 2014). Terms that are strongly associated with each other are by default placed in the same cluster, demonstrating an emergent view of the existing literature of the DIY science.

CLUSTERS OF RESEARCH IN DIY SCIENCE – FINDINGS AND DISCUSSION

In this study the software clearly produced four major clusters of existing DIY science research, the (i) green cluster highlights *how DIY science is being used in education and professional development*, (ii), the yellow cluster denotes the *DIY science culture and its implications*, (iii) red cluster contains discussions related to *operationalizing DIY science through DIY labs and other practices*, and (iv), blue cluster covers the *technologies of DIY labs*. To provide a thorough investigation of the areas of research, each cluster is analysed according to the themes that are presented within each respective cluster. The results of the thematic analysis are represented visually in Figure 1. In the map, the frequency of occurrences is represented by the size of the noun phrase, i.e. larger circles represent higher number of occurrences of the term.

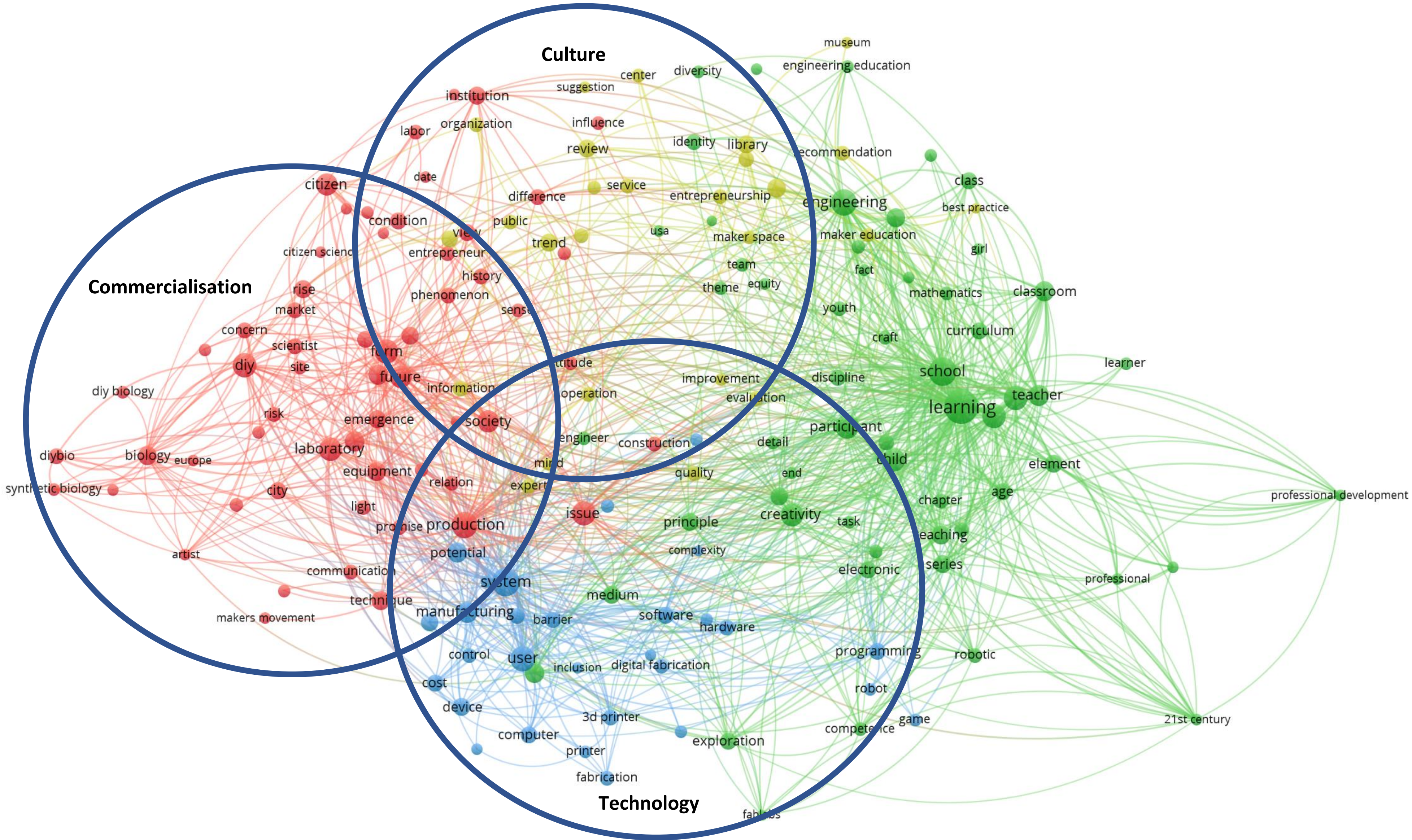

Figure 1. The bibliometric content mapping of industry convergence scholarship

The overlaps between clusters are evident in Figure 1 and a number of terms appear in the overlapping sections of the circles that depict the Culture, Technology, and Commercialisation. While each of the terms is presented in a single colour, the analysis shows links to other terms presented in a different colour – indicating the potential for overlapping themes. For example, ‘society’ appears in the centre of the three clusters due to the inherent nature of DIY science in its embeddedness within the society (though often viewed through different lens’). The overlap between two clusters, for example ‘production’ and ‘potential’ terms between commercialisation and technology refer to terms that are naturally related to both clusters. Production and its potential are both interesting themes for technology and its commercialisation in DIY science. It is more common to associate the term ‘potential’, for example, in the studies that look at DIY science from the ‘technology’ perspective rather than commercialisation or cultural perspectives of the same scholarship. Therefore, the term ‘potential’ is in the blue ‘technology’ i.e. ‘Technologies of DIY labs’ cluster. We understand that these overlaps may be broad in nature, thus it is necessary to incorporate the discussions of select papers in each cluster to not only delineate the clusters more clearly and deliver the map or classification of the DIY science scholarship but also to shed light into this pertinent emerging topic through a number of important studies in this field.

DIY science in education and professional development (green)

A large part of the DIY science literature discusses its interrelationship with education and professional development. There is considerable interest in finding ways to engage more people in science – particularly children. For example, educators have shown that involving students in DIY science activities such as building a robot in a fab lab or using 3D printers to create components leads students to further their interest in STEM areas (Stevenson et al., 2019). The green cluster is a conversation spanning both the practice of science and education studies, however, as this is a journal that focuses upon technology and strategy related issues, we do not build any suggestions concerning future research directions in this area.

Culture: DIY science culture and its implications (yellow)

Starting with the smallest of the three clusters that we consider in this paper, the yellow cluster addresses cultural issues as they pertain to DIY science. Observing the phenomena through a cultural lens, DIY science is clearly associated with entrepreneurship (e.g. Fox, 2014; Ng et al., 2020). For example, Wolf-Powers et al. (2017) provide three types of enterprises with specific reference to the maker movement; each with a different contribution to local and regional economic development. While Browder et al. (2019) demonstrate that in the case of DIY labs, digitization, economization, collaboration, and user-innovation are the enabling forces in the driving of knowledge creation and entrepreneurial activities.

However, the focus across some of the literature recognizes that these are not always traditional entrepreneurial ventures. The ‘counterculture’ notion element does pervade parts of the DIY science movement – which may partially explain why participants, even when highly qualified, engage with DIY labs, rather than traditional corporate research programs or university research centres (Damm et al., 2013; Lhoste, 2020). Diversity is a theme that emerges in relation to this cluster and existing literature speaks to the power of diverse groups of individuals coming together in ways that rarely occur in more targeted corporate research undertaking. DIY science provides opportunities to potentially marginalized groups that may not otherwise be able to engage in science (e.g., Vessal et al., 2020) and through a gender lens, it is interesting to note that e-textiles is female-dominated practice, which in turn questions the traditional notions of male-dominated STEM disciplines (Buchholz et al., 2014). This theme of the importance of diversity (often studied via cultural diversity) in terms of entrepreneurial outcomes and regional development is a growing area of interest in the entrepreneurship and economic geography literature (Audretsch, et al., 2019).

A theme of 'public' is also present in this cluster and there is a tension between how open certain projects may be, whether the general public can become involved and the type of role that interested members of the public may play (You et al., 2020; Wu & He, 2020). After all, if DIY science is about the democratisation of science, then the erection and maintenance of barriers that make DIY labs no more accessible to interested individuals than the institutional model that currently dominates scientific activities, then maybe we are further from the ideals of DIY science than some have suggested. While knowledge spillovers are an issue in all research endeavours, it is possible to manage these spillovers more tightly in a corporate or university environment where there are clear systems and procedures (Battke et al., 2016), but without these in place, the potential value capture available to entrepreneurs may lessen their commitment to the DIY model (Giusti et al., 2020). Thus, whilst this 'culture' cluster of research addresses a number of themes, looking forward, we suggest some possible research questions may include:

(i) *What makes DIY science an attractive option for qualified scientists?*

(ii) *How does the diversity of participants in the DIY lab impact the quality of research programmes, the outcomes of projects and the longevity of the DIY lab?*

(iii) *How can DIY labs effectively engage the public (without compromising security and limiting knowledge spillovers/intellectual property leakages)?*

Commercialisation: Operationalising DIY science through DIY labs (red)

The red cluster covered a range of issues pertaining to operationalising DIY science and there is a significant focus on the commercialisation potential of DIY science. At a macro level, DIY science has been linked to regional development (Fox, 2014; Wolf-Powers et al., 2017) and it is for this reason that a number of more formalised DIY science operations receive some level of government funding.

However, the dominant discourse is one around the entrepreneurial opportunities that exist. A number of single industry (or limited number of firms) studies highlight how DIY science has been instrumental in creating new businesses (e.g., Galvin et al., 2020; Ng et al, 2020). Without doubt, entrepreneurs are indeed part of making DIY science work. There is, however, an alternative perspective that suggests that participants in DIY labs are not necessarily seeking to maximise any potential monetary benefits that may accrue (Langley et al., 2017; Vessal et al., 2020). This may partially relate to the 'counterculture' notion and/or the manner in which individuals become involved in the DIY science movement – the drivers for which are often not financially oriented. This relates to the concept that DIY science provides an entry point for some more marginalized members of society, people engage for altruistic reasons or sometimes for social reasons (Lee et al., 2016; Lhoste, 2020). Overall, DIY science provides opportunities for entrepreneurs, but given people engage for a variety of reasons, economic benefits are by no means guaranteed. For example, Davies (2018) illustrates that hackers are often more interested in self-actualization and empowerment rather than social change or collective action.

Other themes show in the data presentation around markets such as the degree to which DIY science drives innovations that are either technology-push or market-pull. Existing literature does not seem to delve into this issue extensively as while DIY science presents a “cultural trend that focuses on an individual’s ability to be a creator of things using technology” (Kwon and Lee, 2017: 318), there are example such as the ‘Nightscout project’ (Lee et al., 2016) where the innovation was developed to meet a clear market need.

Finally, there is a theme around the key inputs (or barriers) for DIY science in the form of labour, equipment and funding (Cheah et al., 2020; Meyer & Wilbanks, 2020). In terms of potential barriers, Kwon and Lee (2017) suggest that technological and institutional changes have significantly reduced the barriers for people wishing to engage in DIY science. Cheaper technology, access to crowdfunding and other non-traditional funding sources are bringing more people into DIY science (Sarpong & Rawal, 2020). Even in terms of labour, there are some opportunities to build operations using the same principles as citizen science. Taken together, this means that DIY scientists are able to undertake projects with far fewer resources than may have been required a decade or two ago, or what may be required in a corporate setting (Schön et al., 2014).

Possible research questions aligning with this cluster may include:

(i) *How do DIY science participants select projects to undertake?*

(ii) *How do commercial imperatives impact DIY labs activities?*

(iii) *What are the barriers to commercialisation of DIY science?*

Technology: Technologies of DIY labs (blue)

This cluster essentially discusses the technology that is involved in DIY science. A key issue is the increased accessibility to advanced technologies that are available to DIY scientists. As an example, people are able to link up with 3D hubs where individuals share their 3D printing resources and also provide design services (Hamalainen et al., 2018). The key is obviously undertaking the type of projects that can be supported with the technology in place. The possible lower level of technology compared to what may be available in a corporate or university laboratory is often not a concern as DIY labs have been linked to extensive radical or breakthrough innovations (e.g., Anderson, 2012; Von Hippel 2005) and creating new sub-industries in respect of medical devices, sports gear, and typesetting (Gorman, 2011; Nascimento et al., 2014).

Beyond questions around access to technology, types of technologies in use and the potential of these technologies, a key theme is the cost and barriers to accessing the technology. Much of the technology in use is relatively affordable, but there are clearly exceptions and the frequent coverage of the cost of technology and facilities more broadly across the literature suggests that this will remain a potential barrier for many to be able to effectively engage in DIY science (Fox, 2014).

Coupled with the technology choices are ethical concerns. Biological research has attracted attention due to biosecurity (Sarpong et al., 2020), and now as health related science relies increasingly upon algorithms and technology, how far do we allow individuals to take health diagnosis on their own, and who bears the ultimate responsibility for these technologies (White, 2019)? There are also broader ethical concerns such as sustainability. For example the barriers to recycling of 3D printing waste prevent makers from sustainable operations (Peeters et al., 2019).

Technology is going to continue to remain a key issue in DIY science given the comparison point will always be fully funded research efforts in corporate or university settings. Possible research questions pertaining to technology issues could include:

(i) *Do technology access barriers hamper the potential of DIY science?*

(ii) *How do DIY lab entrepreneurs maneuverer their way around technology access issues to compete with large scale corporate R&D efforts?*

(iii) *Can ethical issues be managed in a DIY science setting without institutionalising the activities within a DIY lab?*

Figure 1 shows considerable overlaps between the different themes in the three discussed clusters, we suggest that these three clusters discussed interrelate. For example, the unique culture of DIY labs impacts the commercial dimension attracting people into the DIY activities that are often less profit (or even successful outcome) oriented. The potentially reduced commercial opportunities is possibly both a function of the technology available and the technology in use may limit the commercial prospects of the research. In terms of the link between culture and technology, the counterculture mentality and the hacker and maker approaches to using technology possibly align.

In reviewing many of the papers from each of the three key thematic areas, the lack of clarity around what is covered by DIY science and DIY laboratories constitutes a significant challenge. There seem to be almost two simultaneous streams of activity. The first is around more formalised structures that may be part of a recognized group such as Fab Labs, Hackerspaces and DIY biolabs (You et al., 2020). Many of these spaces receive funding of some sort and while they may welcome a diverse clientele, they are still a somewhat institutionalised model (albeit one that is more accessible and possibly less restrictive than what is found in a corporate or university environment). There is a second stream of literature which covers the DIY science whereby participants find low cost ways of engaging with research. This stream of literature refers to alternative spaces in which DIY science may be practiced and suggests that garages, basements, home workshops, libraries, etc., are all potential options (Nascimento et al., 2014).

These two models for DIY science are seen in all three thematic subfields considered, but they vary considerably across numerous dimensions – the technology available, number of people involved and with whom a DIY scientist may interact, the funding available, the rationale for engaging in DIY science (i.e. for a start-up business versus out of interest to develop products, but not for extensive financial gain).

While both approaches to DIY science do support the democratisation of science, discussing the working of an operation such as La Paillasse with funding from Roche and government support in the same way as someone spending their weekends tinkering in their home workshop limits the potential for the field to coalesce around key issues. For example, the potential for DIY science to be part of new STI policies will be limited whilst we take such an all-encompassing view. It may therefore be appropriate to at least differentiate between DIY science undertaken in formal research spaces that have been established for the purposes of supporting DIY science versus informal or opportunistic spaces based at an individual's home or in a space not necessarily recognised as a location for DIY science such as a library. Addressing key research questions to each group individually is likely to produce more fruitful results by allowing researchers to engage with these two different streams and recognising that they each bring their own strengths and weaknesses to the DIY science story.

CONCLUSION

While interest in DIY science is growing exponentially (Meissner et al., 2020), it has struggled to gain widespread interest in much of the business literature until very recently. Part of this can be explained on the basis that interest in the phenomena came initially from the science/engineering field, quickly coupled with education research. This has expanded more recently, but the field is still plagued with challenges concerning nomenclature. Part of this is a simple function of the diversity of the science undertaken under the umbrella of DIY science. The result is a highly fragmented field with most research considering a limited number of industry or firms; and almost always focused upon one type of science.

On this basis, undertaking a comprehensive bibliometric content analysis provided an integrated picture of how past research could be conceptualised along thematic lines, whilst presenting avenues for future research opportunities. From a business perspective, it is only relatively recently that we have significant attempts to view the DIY science phenomena through the lens of different frameworks/concepts. For example, recent work has seen DIY science discussed in terms of business models (Ng et al., 2020; You et al., 2020), knowledge spillovers (Galvin et al., 2020), innovation outcomes (Cheah & Li, 2020) and communities of practice (Wulandhari et al., 2020). Interestingly, this business-oriented research has not progressed sufficiently for it to form a notable dimension in any of the themes beyond entrepreneurship. On the basis of this emerging business-oriented literature and the concepts identified in the 'culture' theme, we suggest the greatest opportunities for further development may lie in both considering how DIY science may be used to further a range of desirable outcomes (e.g., economic development) and applying existing theoretical frameworks to the DIY science phenomena.

Given the diversity of terminology and the academic outputs pertaining to DIY science, this research does suffer from the uncertainty as to whether we used all of the correct terms to capture the breadth and depth of published work in the field, but without drawing irrelevant papers into the sample. Given the relatively small sample size of our bibliometric study, we were able to view many of the papers, however, establishing appropriate boundaries remain a challenge in all bibliometric research.

Looking forward, we have suggested a series of research questions that are both relevant to DIY science and draw upon wider bodies of knowledge. Further development of our understanding of how, when and why DIY science and different forms of DIY labs work if it is to be an integral part of governments' STI policy. If this is done, and coupled with some work only very recently completed, then a future bibliographic study that considers the period prior to 1980 and the period from 2020 onwards is likely to present considerably different patterns.

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