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ORIGINAL RESEARCH

A Bibliometric Analysis of Research on CRISPR in Social Sciences and Humanities

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Abstract

The rise of CRISPR not only opens up multiple opportunities for genetic editing but also results in potentially threatening or controversial applications. Research needs to be done in order to appreciate how CRISPR affects the identity and role of individuals within society and reshapes social, political, and economic regimes. A bibliometric analysis of articles on CRISPR published in academic journals in the period 2012-2020 helps identify the main research themes on genome editing that have been addressed in social sciences and humanities so far. Results suggest that CRISPR studies have primarily focused on normative and ethical issues, together with more specific attention toward issues of public perception, trust toward science, regulation and governance of critical applications, and, especially, around the manipulation of the genome of human embryos. Results also suggest that issues of commercial, cultural, and geopolitical sorts have been left relatively unattended so far, instead. Attention to the implications of CRIRPS on such areas should inform the future social sciences and humanities research agenda on genome editing.

Keywords: CRISPR; genome editing; social sciences; humanities; bibliometric analysis

Introduction

The fields of molecular biology, biochemistry, and genetics have been revolutionized by the emergence of the CRISPR technique for genetic editing. CRISPR provides a novel approach to edit parts of a genome in a way that is more accurate, efficient, and economical than alternative methods.[1] The opportunities opened up by CRISPR include applications in such different areas, for example, precision medicine, screening and diagnostics, crop improvement, and breeding.2,3 CRISPR, however, also results in potentially threatening or controversial practices, such as, for example, bioterrorism, biohacking, and eugenics.[4] Issues arise, therefore, around the impact of CRISPR on the society and the economy.

The scholarly literature on CRISPR (and genetic editing more generally) in natural sciences skyrocketed since 2012, when components of the CRISPR-cas9 system were isolated and shown to be programable to cut specific sites in isolated DNA.[5] Research in social sciences and humanities proliferated when it became apparent that the new technique would bring about radical innovations and disruptive effects to existing ecological, regulatory, and industrial regimes. The rise of CRISPR triggered a number of questions, for example, around the relationship between genetic editing and ethics[6], economics[7], regulation,[8] and governance.[9] After about a decade since the discovery of CRISPR, it is timely to look back at social sciences and humanities research done on the implication of genetic editing for humans, other living species, and the environment so far, and to indicate directions for future research.

Engagement of social scientists and scholars from the humanities with genetic editing is welcome because of various reasons. First, the rise of CRISPR provides the opportunity to study the refinement, adoption, diffusion, and regulation of an emerging technology.[10] Second, the

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implications of CRISPR are potentially so revolutionary that multiple disciplinary, social and cultural perspectives should be included into the debate about the regulation and governance of genetic editing, in a way that overcomes the limitations that afflicted the Asilomar experience.[11] Finally, the issues that arise from CRISPR call for a coordinated policy and regulatory response from different countries and across government layers. Social sciences and humanities research can provide valuable insights into the role of issue framing, policy narrative, policy communication, and other factors that influence how new regulatory policies for genetic editing are made.

This study reviews the research done by social scientists and scholars from the humanities on CRISPR in the period 2012-2020 and, relatedly, provides evidence of main research themes that help shape a future research agenda. Next section will outline the method followed in this study. The following sections will illustrate the results of the analysis and discuss the findings. The final section will draw the conclusions.

Method

The CRISPR opens up venues for applications that pose issues around, for example, mosaicism and other flaws of organisms,[12] uncontrolled transmission of genetic edits across countries[13] and generations,[8] use of genetic editing for military purposes,[14] exacerbation of productivity gaps between gene-edited crops and other varieties,[15] engineering of gene-edited mushrooms that escape regulations,[16] and the birth of genome-edited babies.[17] From a social sciences and humanities perspective, these controversial applications trigger fundamental questions about the regulation and governance of genetic editing, like for example, What should CRISPR be used for? How much risk that arises from unknown effects of CRISPR is tolerable? What institutional regimes facilitate responsible research of CRISPR applications while protecting individuals and the environment from undesired effects? How can coordinated policies on genetic editing be attained at the global scale? Research in social sciences and humanities can help address these questions by investigating the normative and ethical dilemmas that arise from CRISPR applications within specific historical and institutional context conditions.

This bibliometric analysis of research on CRISPR in social sciences and humanities was carried out by searching for journal articles containing the word "CRISPR" in the title or abstract in the period 2012-2020 in three databases, namely, Web of Science (WoS), Scopus, and Dimensions. Search in WoS was limited to the Social Science Citation Index and Arts & Humanities Citation Index. Search in Scopus was limited to the following sections: economics; econometrics and finance; arts and humanities; business, management, and accounting; and social sciences. Search in Dimensions was limited to the following categories: economics; commerce, management, tourism, and services; law and legal studies; studies in human society; and philosophy and religious studies. Other main search engines (Google Scholar and Microsoft Academic) were not used because they do not provide a way to filter search results by discipline or subject area. The research was carried out in adherence to ethical guidelines and approved by the home institution of the authors.

Table 1 provides summary statistics of the search results. Search results were analyzed using R's package Bibliometrix[18] to identify most frequent journal sources and cited articles. In order to map out research on CRISPR, search results were analyzed via a co-occurrence analysis of keywords and bibliographic coupling using VOSviewer.[19] The co-occurrence analysis of keywords resulted in a network of keywords where their relatedness depends on the number of articles in which they occur together. A thesaurus helped consolidate keywords into fewer numbers. The bibliographic coupling analysis resulted in a network of journal articles where their relatedness depends on the number of references that they share. Other methods of analysis (ie, relatedness based on number of coauthored articles or on number of times articles cite each other or on the number of times articles are cited together) were discarded because of the relative newness of studies on CRISPR in social sciences and humanities. Metrics of the networks were obtained using Gephi.

Results

Search results showed that most frequent venues of publication of articles on CRISPR in social sciences and humanities were journals in the field of ethics (Table 2). Some of the top 10 most cited articles (Table 3) relate to landmark studies on the discovery and development of CRISPR published in *Science*,[5,24,25,34] *Nature*,[1] *Cell*,[26] and *Protein and Cell*,[23] while others refer to studies on the implications of CRISPR applications on humans, other living species, and the environment.[20,21,27,30,36] The analysis of co-occurrence of keywords from WoS resulted in a network that consisted of 77 keywords (548 edges, graph density 0.187) grouped into six clusters (Table 4). The analysis of co-occurrence of keywords from Scopus resulted in a network that comprised 207 keywords (4,855 edges, graph density 2.28) grouped into five clusters (Table 5). Search results from Dimensions do not currently include keywords.

Table 1. Summary statistics of the search for articles in social sciences and humanities containing "CRISPR" in the title or abstract in WoS, Scopus, and Dimensions from the period 2012 to 2020

	WoS	*Scopus*	*Dimensions*
No. documents published in the year			
2012	0	0	1
2013	0	1	1
2014	1	1	4
2015	10	9	45
2016	10	20	104
2017	18	32	166
2018	33	52	267
2019	54	96	304
2020	56	82	351
Total number of documents	182	293	1,243
No. sources	101	106	422
Average years from publication	2.48	2.48	2.62
Average citations per documents	6.281	2.549	3.809
Average citations per year per document	1.606	0.7049	0.9598
Authors	654	599	2,180
Authors of single authored documents	69	149	523
Authors of multiauthored collaboration	585	450	1,657

Table 2. Top 10 journals by number of articles in social sciences and humanities containing "CRISPR" in the title or abstract in WoS, Scopus, and Dimensions from the period 2012 to 2020

	WoS	*Scopus*	*Dimensions*
1	Bioethics (8)	Genetic Engineering and Biotechnology News (54)	American Journal of Bioethics (77)
2	Biology & Philosophy (8)	International Journal of Biological Macromolecules (28)	Frontiers in Genetics (37)
3	Science and Engineering Ethics (8)	Biology and Philosophy (8)	Bioethics (32)
4	American Journal of Bioethics (7)	Science and Engineering Ethics (8)	The Hastings Centre Report (31)
5	Journal of Bioethical Inquiry (5)	AMA Journal of Ethics (7)	Science and Engineering Ethics (23)
6	Journal of Responsible Innovation (5)	Perspectives in Biology and Medicine (7)	Journal of Responsible Innovation (22)
7	Nanoethics (5)	Biolaw Journal (6)	Nanoethics (21)
8	Zygon (5)	Zygon (6)	Cambridge Quarterly of Healthcare Ethics (20)
9	Bulletin of the Atomic Scientists (4)	Bioethics (5)	Perspectives in Biology and Medicine (20)
10	Environmental Communications (4)	Journal of Bioethical Inquiry (5)	The New Bioethics (18)

Bibliographic coupling analysis was carried out on the search results from Dimensions, which largely surpassed, in number of articles, those from WoS and Scopus. The analysis resulted in a selection of 54 articles, but the largest network of connected articles consisted of 38 articles only (125 edges, graph density 0.178) (Fig. 1), which were grouped into six clusters (Table 6). Table 7 shows, for each article (node), the degree (number of links connected to the node), weighted degree (number of links connected to the node, weighted by number of citations), closeness centrality (average length of the shortest path between the node and other nodes), and betweenness centrality (number of times a node is crossed by each of the least cost paths). The nodes are ranked by betweenness centrality, which helps indicate the relative importance of a node to connect different parts of the network.

Discussion

The analysis of co-occurrence of keywords provides some insights into the issues about CRISPR that are tackled in social sciences and humanities research. The analysis of WoS data suggests the presence of research interest toward: public perception and attitudes toward CRISPR, consumer acceptance of genetically edited products, trust toward sciences, risk, and the precautionary principle (in cluster 1); the uses of CRISPR, including preimplantation genetic diagnosis, assisted reproduction, gene therapy, human enhancement, and eugenics (in cluster 2); the experimentation with CRISPR on animals like mice and zebrafish (in cluster 3); the use of CRISPR to research the genetic determinants of disorders like autism and schizophrenia (in cluster 4); the origin of CRISPR as a defense immune system (in cluster 5); and the use of gene drive to tackle infectious diseases like malaria (in cluster 6). The analysis conducted on Scopus data suggests the identification of themes like: how CRISPR works and its effects on genetic materials (in cluster 1); governance issues around the use of CRISPR in humans for various purposes—from infertility to human enhancement (in cluster 2); the mechanisms that underpin CRISPR, such as

Table 3. Top 10 cited articles in social sciences and humanities containing "CRISPR" in the title or abstract in WoS, Scopus, and Dimensions from the period 2012 to 2020

	WoS	*Scopus*	*Dimensions*
1	Baltimore D, Berg P, Botchan M, et al., 2015[20]	Jinek M, Chylinski K, Fonfara I, et al., 2012[5]	Baltimore D, Berg P, Botchan M, et al., 2015[20]
2	Lanphier E, Urnov F, Haecker SE, et al., 2015[21]	National Academies of Sciences, Engineering and Medicine, 2017[22]	Liang P, Xu Y, Zhang X, et al., 2015[23]
3	Liang P, Xu Y, Zhang X, et al., 2015[23]	Doudna JA, Charpentier E, 2014[24]	Lanphier E, Urnov F, Haecker SE, et al., 2015[21]
4	Cong L, Ran FA, Cox D, et al., 2013[25]	Hsu PD, Lander ES, Zhang F, 2014[26]	Jinek M, Chylinski K, Fonfara I, et al., 2012[5]
5	Jinek M, Chylinski K, Fonfara I, et al., 2012[5]	Ledford H, 2015[1]	Doudna JA, Charpentier E, 2014[24]
6	Doudna JA, Charpentier E, 2014[24]	Liao SM, 2010[27]	Ledford H, 2015[1]
7	Ledford H, 2015[1]	Cong L, Ran FA, Cox D, et al., 2013[25]	Ma H, Marti-Gutierrez N, Park SW, et al., 2017[28]
8	Ran FA, Hsu PD, Wright J, et al., 2013[29]	Jasanoff S, Hurlbut JB, 2018[30]	Cong L, Ran FA, Cox D, et al., 2013[25]
9	Lander ES, 2015[31]	Koonin EV, 2019[32]	Esvelt KM, Smidler AL, Catteruccia F, et al., 2014[33]
10	Mali P, Yang L, Esvelt KM, et al. 2013[34]	Lander ES, 2016[35]	Lander ES, Baylis F, Zhang F, et al., 2019[36]

those of gene deletion and gene silencing (in cluster 3); and regulatory issues that arise from applications of CRISPR, from agriculture to health to invasive species control (in cluster 4).

The analysis of bibliographic coupling results in a network of journal articles that provides indications of influential studies on CRISPR research. Articles addressed issues concerning human genome editing, human enhancement, and bioethics (in cluster 1), genetic editing in agriculture (in cluster 2), relationships between genetic editing and GMOs and related implica- AQ3
tions on the bioeconomy (in cluster 3), gene drive and eradication of invasive species (in cluster 4), application of CRISPR in human reproduction (in cluster 5), and security, regulation, and governance (in cluster 6). Those articles that rank higher in betweenness centrality—which suggests that they play an important role to connect areas of inquiry—especially focus on issues about the use of CRISPR on human embryos,[70,75] on the application of CRISPR on gene drive,[63,64,67] and on regulatory policy and governance issues.[8,39,48]

This bibliometric analysis offers an empirically based approach to map out how CRISPR has been researched in social sciences and humanities so far. Results suggest that the rise of CRISPR triggered a variety of interest. Many studies have been prominently concerned with CRISPR applications that are intended to bring about beneficial effects to individuals (eg, preimplantation genetic diagnosis, assisted reproduction, gene therapy, human enhancement, and eugenics) or to alter the natural environment in ways that are beneficial to individuals or groups (eg, the eradication of invasive species and the improvement of crops). Relatively fewer studies have paid focused attention to CRISPR applications that are intendedly harmful, such as, for example, those related to terrorist threats.[76] Most studies tackle the normative and ethical implications of CRISPR, primarily focusing on issues not only that arise from the manipulation of the genetics of human embryos but also that relate to the editing of other living organisms that could trigger the extermination or extinction of species or unpredictable harms to ecosystems.

The fact that most studies in social sciences and humanities pay attention to normative and ethical issues arising from CRISPR is hardly surprising. As other waves of innovation in genetics (zinc finger nucleases/TALENs, gene therapy, GMOs, and recombinant DNA), CRISPR opens up venues for novel applications whose effects and implications are not completely understood yet, or which clash with existing value systems and deontological principles. On the other hand, the bibliometric analysis shows that social sciences and

Table 4. Clusters of keywords in articles in social sciences and humanities containing "CRISPR" in the title or abstract in WoS from the period 2012 to 2020

Cluster	*Keywords*
1	Agriculture, attitudes, bioethics, biotechnology, consumer acceptance, future, GMO, governance, health, information, perceptions, policy, precautionary principle, preferences, risk, science, trust
2	Assisted reproduction, cells, embryos, enhancement, ethics, eugenics, gene therapy, genome editing, germline, human enhancement, nonidentity problem, preimplantation genetic diagnosis (PGD), reproduction, selection, therapy
3	Anxiety, behaviour, dysregulation, expression, genes, history, impact, mice, model, mouse, mutations, proteins, regulation, spectrum disorders, synaptic-transmission, zebrafish
4	Autism, autism spectrum disorder, CRISPR, elements, evolution, generation, human genome, morality, pluripotent stem-cells, schizophrenia, transmission
5	Biology, conception, defense, disease, DNA, genome, immune-system, repeats, strategies
6	Endonuclease, gene drive, infection, informed consent, malaria, replacement, synthetic biology, system

Table 5. Clusters of keywords in articles in social sciences and humanities containing "CRISPR" in the title or abstract in Scopus from the period 2012 to 2020

Cluster	*Keywords*
1	Amino acid sequence, bacterial enzyme, bacterial protein, bacterial proteins, bacterial strain, bacterium isolate, biocatalysis, biochemical analysis, biodegradation, biosynthesis, carboxylesterase, catalysis, characterization, chemistry, cloning, molecular, controlled study, detergent, enzyme activity, enzyme analysis, enzyme immobilization, enzyme purification, enzyme specificity, enzyme stability, enzymology, escherichia coli, ester derivative, esterase, esterases, gene expression, regulation, gene overexpression, hydrogen-ion concentration, hydrolysis, immobilization, in vitro study, isolation and purification, kinetics, lipolysis, metabolism, metagenomics, metal, metals, models, molecular, molecular cloning, molecular dynamics, molecular model, molecular weight, nonhuman, nucleotide sequence, organic solvent, ph, phylogeny, protein conformation, protein function, protein motif, protein stability, purification, recombinant protein, recombinant proteins, sequence alignment, sequence analysis, sequence homology, stereoisomerism, structure analysis, substrate specificity, synthesis, temperature, thermostability, triacylglycerol lipase, unclassified drug, wheat bran
2	Adult, adverse event, Asilomar conference, autonomy, bioethical issues, bioethics, biomedical enhancement, child, child parent relation, China, clustered regularly interspaced short palindromic repeat, clustered regularly interspaced short palindromic repeats, conflict, CRISPR cas system, designer babies, dissent and disputes, embryo, embryo research, enhancement, ethical analysis, ethical theory, ethics, ethics, medical, eugenics, female, gene therapy, genetic enhancement, genetic therapy, genome editing, genome, human germ cell, germ cells, germ line, history, history, 20th century, human, human cell, human embryo, human enhancement, human experiment, human genome, humans, infertility therapy, knowledge, legislation and jurisprudence, male, medical ethics, molecular genetics, moral status, morality, morals, parents, patent, philosophy, policy, politics, preimplantation genetic diagnosis, procedures, psychology, public opinion, reproduction, reproductive techniques, assisted, trust, uncertainty
3	Animal cell, archaea, article, bacteria, bacterial genome, bacterium, biological model, bombyx mori, cell proliferation, CRISPR associated protein, crispr-cas9 system, DNA, DNA modification, epigenetics, evolution, evolution, molecular gene control, gene deletion, gene expression, gene knockout, gene sequence, gene silencing, gene targeting, genes, genome, genomics, guide RNA, immune system, immunity, Lamarckian, messenger RNA, models, molecular evolution, mouse, polyacrylamide gel electrophoresis, protein, protein analysis, protein expression, RNA, guide, western blotting
4	Agriculture, animal, animalia, animals, Australia, biodiversity, bioengineering, biomedical research, biomedicine, biotechnology, conservation, CRISPR, CRISPR/cas-9, European union, gene drive, gene drive technology, genetically modified organism, germline, germline gene editing, GMO, government regulation, informed consent, invasive species, malaria, medical research, perception, precautionary principle, public health, regulation, synthetic biology, trends, united states

humanities research has been relatively silent toward other implications of CRISPR of commercial, cultural, and geopolitical sorts. These gaps provide some ways to suggest directions for the future research agenda. Each of these areas will be discussed in turn.

First, applications of CRISPR may result in a stream of new food and feed products, which can outcompete existing ones because of higher productivity, less production costs, and higher nutritional content. Successful commercial applications of CRISPR may have important rep on existing industries and international trade in such areas as, for example, patenting of genetically edited seeds and other organisms, certifications, custom controls, and disruption to incumbent industrial regimes. Genetically edited food and feed products may dramatically squash the competitiveness of existing farmers, with potentially devastating effects on the conditions of livelihood especially in developing countries. Various issues would need to be addressed around these implications, such as, for example, how CRISPR products will affect existing agriculture and food markets, how existing regime of patents, health and safety regulations, and international trade agreements will adjust to the rise of CRISPR products, what attitudes the public have toward genetically edited food and feed products, and what policies governments can pursue in order to cope with the rise of CRISPR products.

Second, applications of CRISPR may also result in profound cultural changes. The development of CRISPR applications that deliver enhancements of the human

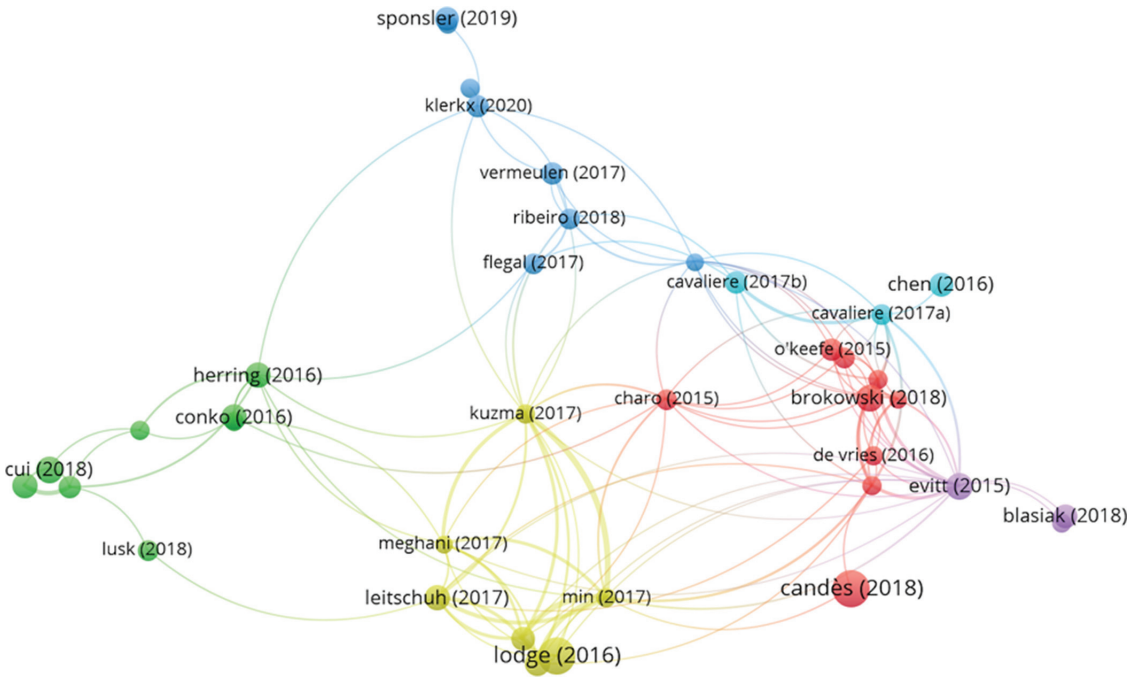

FIG. 1. Clusters of articles in social sciences and humanities containing "CRISPR" in the title or abstract in Dimensions, from the period 2012 to 2020, threshold set at minimum 20 citations. Labels indicate only the first author in case of multiple authors publication.

Table 6. Clusters of articles in social sciences and humanities containing "CRISPR" in the title or abstract in Dimensions resulting from the bibliographic coupling analysis from the period 2012 to 2020

Cluster	*Articles*
1	Brokowski C, 2018[37]; Candes E, Fan Y, Janson L, et al., 2018[38]; Charo RA, Greely HT, 2015[39]; De Vries RG, Tomlinson T, Kim HM, et al., 2016[40]; Harris J, 2016[41]; Hildt E, 2016[42]; Krishan K, Kanchan T, Singh B, 2016[43]; O'Keefe M, Perrault S, Halpern J, et al., 2015[44]; Sparrow R, 2019[45]
2	Flegal JA, Gupta A., 2018[46]; Fraser A, 2019[47]; Klerkx L, Rose D, 2020[48]; McLeod C, Nerlich B, 2017[49]; Ribeiro B, Bengtsson L, Benneworth P, et al., 2018[50]; Rose DC, Morris C, Lobley M, et al., 2018[51]; Sponsler DB, Grozinger CM, Hitaj C, et al., 2019[52]; Vermeulen N, Haddow G, Seymour T, et al., 2017[53]
3	Conko G, Kershen DL, Miller H, et al., 2016[54]; Cui K, Shoemaker SP, 2018[55]; Herring R, Paarlberg R, 2016[56]; Lusk JL, McFadden BR, Wilson N, 2018[57]; Wesseler J, von Braun J, 2017[58]; Wong AYT, Chan AWK, 2016[59]; Zetterberg C, Björnberg KE, 2017[60]; Zilberman D, Gordon B, Hochman G, et al., 2018[61]
4	Burt A, Coulibaly M, Crisanti A, et al., 2018[62]; Kuzma J, Gould F, Brown Z, et al., 2018[63]; Leitschuh CM, Kanavy D, Backus GA, et al., 2018[64]; Lodge DM, Simonin PW, Burgiel SW, et al., 2016[65]; Meghani Z, Kuzma J, 2018[66]; Min J, Smidler AL, Najjar D, et al., 2018[67]; Serr ME, 2019[68]; Scott MJ, Gould F, Lorenzen M, et al., 2018[69]
5	Cavaliere G, 2017a[70]; Cavaliere G, 2017b[71]; Chen SC, Wasserman DT, 2017[72]
6	Blasiak R, Jouffray JB, Wabnitz CC, et al., 2018[73]; Evitt NH, Mascharak S, Altman RB, 2015[8]; MacIntyre CR, Engells TE, Scotch M, et al., 2018[74]

body and capabilities—possibly alongside therapeutic benefits—has been already contemplated as posing normative and ethical issues. In addition, affordability of the CRISPR technique opens up venues for carrying out genetic editing of humans in ways that are unpractical to monitor and relatively uncontrollable. Individuals and groups could become able to undertake genetic editing of themselves and possibly of acolytes of transhumanist movements. The risk that individuals inflict threats of mosaicism and other genetic flaws to themselves and to others would pose issues around the design of regulatory policies that prevent self-inflicted harms. The option to edit own human genome would likely pose cultural issues on such themes as the control of one's (and possibly one's progeny) biological identity and the democratization of the selection of desirable biological traits.

Table 7. Degree, weighted degree, closeness centrality, and betweenness centrality of nodes of the network of articles in social sciences and humanities containing "CRISPR" in the title or abstract in Dimensions, resulting from the bibliographic coupling analysis from the period 2012 to 2020

Node	Degree	Weighted Degree	Closeness Centrality	Betweenness Centrality
Evitt NH, Mascharak S, Altman RB, 2015[8]	19	32	0.57	132.72
Herring R, Paarlberg R, 2016[56]	9	11	0.48	122.59
Klerkx L, Rose D, 2020[48]	7	7	0.49	113.65
Kuzma J, Gould F, Brown Z, et al., 2018[63]	14	42	0.58	99.22
McLeod C, Nerlich B, 2017[49]	12	13	0.51	67.63
Charo RA, Greely HT, 2015[39]	12	14	0.52	58.22
Zilberman D, Gordon B, Hochman G, et al., 2018[61]	5	14	0.36	54.38
Min J, Smidler AL, Najjar D, et al., 2018[67]	11	58	0.53	45.53
Leitschuh CM, Kanavy D, Backus GA, et al., 2018[64]	10	27	0.51	44.78
Cavaliere G, 2017a[70]	11	22	0.47	43.53
Rose DC, Morris C, Lobley M, et al., 2018[51]	2	2	0.34	36.00
Sparrow R, 2019[45]	11	25	0.46	32.88
Meghani Z, Kuzma J, 2018[66]	10	24	0.51	32.63
Conko G, Kershen DL, Miller H, et al., 2016[54]	4	6	0.42	24.55
Wong AYT, Chan AWK, 2016[59]	4	5	0.37	23.05
Lusk JL, McFadden BR, Wilson N, 2018[57]	2	2	0.37	13.97
Hildt E, 2016[42]	11	25	0.47	11.35
Cavaliere G, 2017a[71]	5	10	0.43	10.82
Flegal JA, Gupta A., 2018[46]	4	5	0.43	10.03
Ribeiro B, Bengtsson L, Benneworth P, et al., 2018[50]	6	9	0.45	9.59
Brokowski C, 2018[37]	10	14	0.46	5.50
Krishan K, Kanchan T, Singh B, 2016[43]	8	12	0.44	2.99
De Vries RG, Tomlinson T, Kim HM, et al., 2016[40]	6	6	0.41	2.54
Scott MJ, Gould F, Lorenzen M, et al., 2018[69]	8	27	0.47	1.98
Cui K, Shoemaker SP, 2018[55]	3	5	0.28	1.43
Burt A, Coulibaly M, Crisanti A, et al., 2018[62]	8	36	0.47	1.13
Zetterberg C, Björnberg KE, 2017[60]	3	5	0.39	0.67
Harris J, 2016[41]	8	8	0.45	0.63
Lodge DM, Simonin PW, Burgiel SW, et al., 2016[65]	7	8	0.46	0.00
O'Keefe M, Perrault S, Halpern J, et al., 2015[44]	7	7	0.44	0.00
Vermeulen N, Haddow G, Seymour T, et al., 2017[53]	4	4	0.43	0.00
Candes E, Fan Y, Janson L, et al., 2018[38]	2	2	0.38	0.00
Wesseler J, von Braun J, 2017[58]	2	10	0.27	0.00
Blasiak R, Jouffray JB, Wabnitz CC, et al., 2018[73]	1	1	0.37	0.00
Serr ME, 2019[68]	1	1	0.37	0.00
Fraser A, 2019[47]	1	1	0.33	0.00
Chen SC, Wasserman DT, 2017[72]	1	1	0.32	0.00
Sponsler DB, Grozinger CM, Hitaj C, et al., 2019[52]	1	1	0.25	0.00

Researching the effects of CRISPR on culture will require sensitive attention toward nuances in contemporary discourses as well as in forms of creative expression such as novels, movies, and art.

Cultural implications of CRISPR also call for more intense research effort on the issue of communication of scientific and technological advancements on genome editing to the public. Public perception of opportunities and threats of genome editing would have various consequences on, for example, consumer behavior, attitudes toward environmental integrity and preservation, and policy preferences toward research freedom and funding. Uncertainties about the effects of CRISPR applications could trigger cautionary reactions, which might induce the adoption of restrictive policies toward the use of genome editing and the commercialization of genetically edited products. Research in social sciences and humanities could address these issues and explore the effects of CRISPR communication to public perceptions and policy preferences.

Finally, more attention could be paid, within social sciences and humanities, to geopolitical issues that arise from CRISPR applications. Scientific and technological leadership on genome editing may have important effect on countries' economic competitiveness, military prowess, and strategic advantages. CRISPR applications—for example, from the development of drugs to the one of ethnic bioweapons—can result in tactical advantages to advance a country's interest within the international arena. Accordingly, governments may pursue industrial policies that help advance their countries in the technology race by attracting investment capital and know-how on genome editing, or promoting the cultivation of domestic expertise. Issues that will deserve attention include how genome editing could raise up on a government

agenda, what policy design helps stimulate R&D on genome editing, and how CRISPR would eventually impact the balance of power in the international arena.

Conclusions

This study offers a bibliometric analysis of research done in social sciences and humanities on CRISPR in the period 2012-2020. It also provides some considerations about the future research agenda on the implications of genome editing on the society and the economy. The method of the bibliometric analysis consisted of a co-occurrence analysis of keywords and a bibliographic coupling of journal articles. The results indicate that social sciences and humanities research on CRISPR has primarily addressed normative and ethical implications of the application of genetic editing in various areas. Considerable attention has been placed, in particular, on applications of CRISPR on human embryos and on gene drive. Future research on the implications of CRISPR, instead, could address issues that arise from the commercialization of CRISPR applications, from the cultural effects of the rise of CRISPR, including the role of communication and public perception, and from the geopolitical consequences of CRISPR.

The present study contains some limitations that should be acknowledged. First, bibliographic analysis provides a systematic way to map out the state-of-the-art of scholarly research, but more focused literature reviews in specific areas of inquiry are needed in order to appraise the debate on the effects of CRISPR applications and inform policy choices on the governance and regulation of genetic editing. Second, the present study focused on academic journals only, which may often address relatively narrow issues that arise from CRISPR. Future research may extend attention to monographs, edited books, policy papers, and other documents that could offer alternative insights into perspectives toward CRISPR. Furthermore, the present study focused on academic journal articles that exhibit "CRISPR" in the title or abstract, but part of the social sciences and humanities literature on genome editing might not explicitly refer to CRISPR technology. Future research may extend attention to scholarly works done on the social and economic implications of genome editing more generally. Finally, the present study looked at CRISPR research published in English, but future work could be done on non-English literature which could provide a complementary perspective on genome editing, especially from the Global South.

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