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Yali Zuo
Hebei Minzu Normal University, Chengde, China
The Technology Innovation Center of Cultural Tourism Big Data of Hebei Province
e-mail: zylhaha999@gmail.com
ORCID: https://orcid.org/0000-0003-3240-7246

Illuminating the Progress of Research into Inferentialism: A Systematic Analysis of CiteSpace

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Abstract. The goal of this article is to use the scientometrics software CiteSpace as the analysis tool, studying 317 academic documents about inferentialism from 1999 to 2021 collected in the database Web of Science, to systematically and intuitively present the development trends and hot topics of inferentialism, hoping to explore new ideas and directions. The procedure includes visualizing and analyzing the co-citation networks generated by the 6.1.R3 version of CiteSpace. The knowledge basis and the research front about inferentialism are identified by analyzing the cited references in the major clusters and the citing articles to the major clusters in co-citation networks. The landscape view and timeline view of CiteSpace facilitate the comprehension of the interrelationships among clusters and their temporal evolution, thereby offering a dependable historiographic survey of inferentialism research spanning from theory to practice. Through the utilization of co-keyword network analysis, co-term network analysis, and co-category network analysis, this analytical approach facilitates interdisciplinary research by identifying various topics and disciplines encompassing the application of inferentialism in education, as well as its relation to logic, metaethics, mathematics, perception, and cognition. Through the co-author and co-collaborating country/region of the study, the question of who are the main researchers of a study and which countries/regions are they affiliated with can be answered. It can provide a reference for us to introduce academic resources, carry out cooperation and evaluate academic achievements. All in all, a systematic analysis in CiteSpace is helpful for researchers to capture the salient literature, understand the historical evolution and development trend of inferentialism, and lay a foundation for further research and cooperation according to their interests and specialties.

Keywords: inferentialism; visualization; CiteSpace

I. Introduction

The words ‘inferentialism’ or ‘inferentialist’ were more prevalent after the appearance of Robert Brandom’s book *Making It Explicit* in the 1990s. Some questions, such as how the research field develops and what disciplines and topics are involved in this subject, can be answered, to some degree, by a systematic review of the literature in CiteSpace.

CiteSpace is a tool designed for conducting a visual analytic study of the scholarly literature of a research field, or a discipline, collectively known as a knowledge domain (Chen 2004; Chen 2006), and updated with the theories of scientific

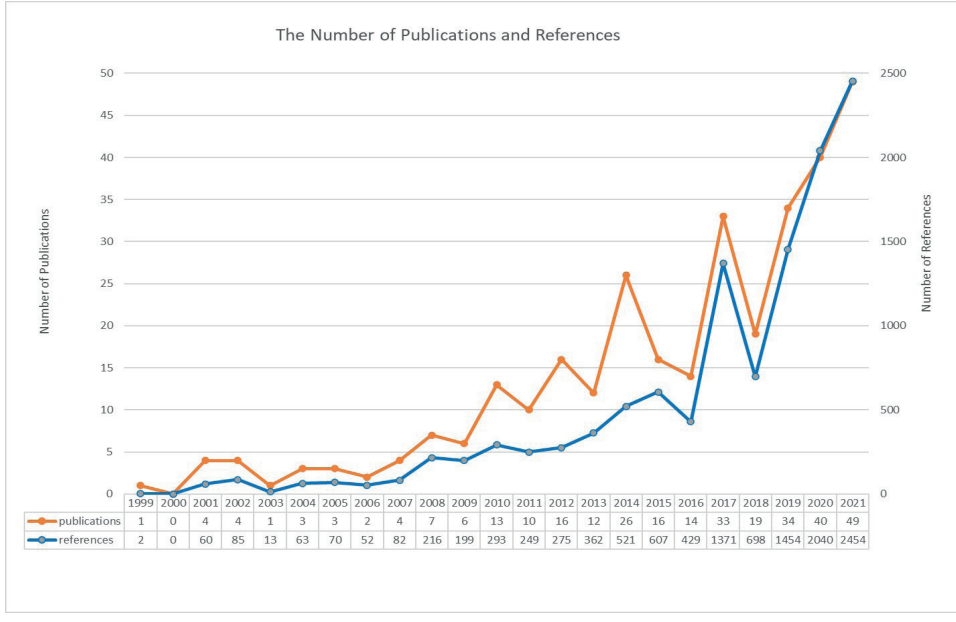
change (Chen 2017). The two outstanding features of CiteSpace are the ability to display the evolution of a field on a knowledge map of a citation network by using multiple-perspectives, time-sharing, and dynamic citation analysis visualization language, and the research frontier represented by the cited references and co-citation cluster as the intellectual base on the map is identified, which shows the intelligibility of the map itself (Chen & Li 2016).

The research procedure of this article includes four steps: (1) preparing data; (2) generating co-citation networks; (3) analyzing the structure and dynamics of co-citation clusters in a multiple-perspective method including Document Co-citation Analysis (DCA), Author Co-citation Analysis (ACA), co-word analysis and collaborating analysis; (4) explaining the results.

Data Collection

The input data is retrieved from citation index databases via the Web of Science Core Collection, which provides cover-to-cover indexing back to 1900 across the world's publications. The data were last updated on February 18, 2022. After refining by Languages (English) and Document Types (Articles or Proceedings Papers or Early Access or Review Articles), 317 results are retrieved from the Web of Science Core Collection for inferentialism (All Fields) or inferentialist (All Fields). The timespan is All years. Indexes are SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, and IC. The content of downloaded documents includes full records and cited references. The number of publications and references over time are shown in Figure 1.

Figure 1 shows the trend of the number of publications and references over time, both with a wave rise. The increase and decrease trends of 1999–2012 and 2015–2021 are consistent. The number of references increases consistently from 2012 to 2015, but the number of publications decreases first, then increases and then decreases, with a peak in 2014. The number of publications and the number of citations both reaches another peak in 2017, and two troughs in 2016 and 2018. The total number of references is 11595, and the average number of references per published article is 37.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
publications	1	0	4	4	1	3	3	2	4	7	6	13	10	16	12	26	16	14	33	19	34	40	49
references	2	0	60	85	13	63	70	52	82	216	199	293	249	275	362	521	607	429	1371	698	1454	2040	2454

Figure 1. The change of publications and references from 1999 to 2021. Own elaboration (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyTnZwbk9WZ1M2eWYrK0dUajhvWCtTUT09&title=Yali%20Zuo's%20pictures%20)

II. Visualization and Analysis

Visualization and analysis contain network visualization, network analysis from a landscape view and timeline view, and results explanation. Each co-citation network is composed of nodes and links. In different networks, the nodes represent different objects, and the links represent the co-citation, co-occurrence, or cooperative relationship between the objects. For example, in a co-cited reference network, a node presents a cited reference, and two nodes with a link between them indicate that they have a co-citation relationship. The main metrics used in CiteSpace include centrality, modularity Q, silhouette S, citation burst, which is a temporal metric, and sigma, which is a hybrid metric depending on both betweenness centrality and citation burst. Centrality, modularity Q, and silhouette S are structural metrics (Chen et al. 2010). Analysis of networks includes an analysis of the value of the metrics. Here, we are more concerned with the result of the measurement than with its mathematical calculation. For the analysis, the methods are similar. Document Co-citation Analysis (DCA) is relatively more detailed here. DCA is a kind of co-citation analysis that can help us find the knowledge basis and research front of inferentialism research.

A progressive Document Co-citation Analysis (DCA)

In DCA, we focus on analyzing salient references as knowledge bases, major citing articles as research fronts, and finding out the evolution of inferentialism research.

CiteSpace supports a progressive DCA in visualization. When building a new project in CiteSpace, the parameters are first set. The option of looking back at a year is set to be unlimited in order to include all the references, while the other options are the default. Then the project is piloted to optimize the selection of parameters according to the operation results. Parameters are set as follows. The time interval from 1999 to 2021 is sliced into 1-year-long segments. The link-retaining factor is 3.0 times the number of nodes. The link strength is measured by the cosine of the angle between the two cited documents (Chen 2004). The references in each time slice are selected based on g-index with a scaling factor k of 25, which presents the top 25 references in the citations selected. The g-index g is the largest rank (where papers are arranged in decreasing order of the number of citations they received) such that the first g papers have (together) at least citations (Egghe 2006). There are 301 qualified records involved in the operation and 8391 valid references (99.70%) in 8406 distinct references. Table 1 shows the time slices and details of individual networks.

Table 1. Time slicing and details of individual networks

1-year slices	criteria	space	nodes	links / all
1999	g = 2, k = 25	2	2	1/1
2000	g = 0, k = 25	0	0	0 / 0
2001	g = 3, k = 25	46	27	81 / 119
2002	g = 3, k = 25	79	29	87 / 161
2003	g = 2, k = 25	13	13	39 / 78
2004	g = 3, k = 25	59	29	87 / 218
2005	g = 2, k = 25	68	26	78 / 140
2006	g = 2, k = 25	50	26	78 / 165
2007	g = 2, k = 25	81	26	78 / 132
2008	g = 5, k = 25	194	37	111 / 195
2009	g = 4, k = 25	187	33	99 / 144
2010	g = 5, k = 25	275	36	100 / 100
2011	g = 5, k = 25	219	36	108 / 149
2012	g = 5, k = 25	240	41	123 / 199
2013	g = 4, k = 25	346	34	76/ 76
2014	g = 5, k = 25	455	50	150/ 427
2015	g = 6, k = 25	524	51	153 / 299

Table 1. Time… (cont.)

1-year slices	criteria	space	nodes	links / all
2016	g = 6, k = 25	383	44	132 / 179
2017	g = 8, k = 25	1193	70	210 / 684
2018	g = 7, k = 25	587	59	177 / 418
2019	g = 8, k = 25	1283	63	189 / 333
2020	g = 9, k = 25	1597	76	228 / 696
2021	g = 7, k = 25	1663	71	213 / 439

Source: CiteSpace 6.1.R3.

Table 1 lists the different g-indexes with a scaling factor k of 25 in each time slice as a pruning configuration to control the size of the network. The largest individual network is in time slice 2020, with a g-index of 9. The two second-largest individual networks are in time slice 2017 and 2019, with a g-index of 8. The merged network has 646 nodes and 2524 links.

Salient nodes visualization in co-citation networks

The time-sliced co-citation networks are visualized in CiteSpace which highlights transitions between adjacent networks, as Figure 2 shows.

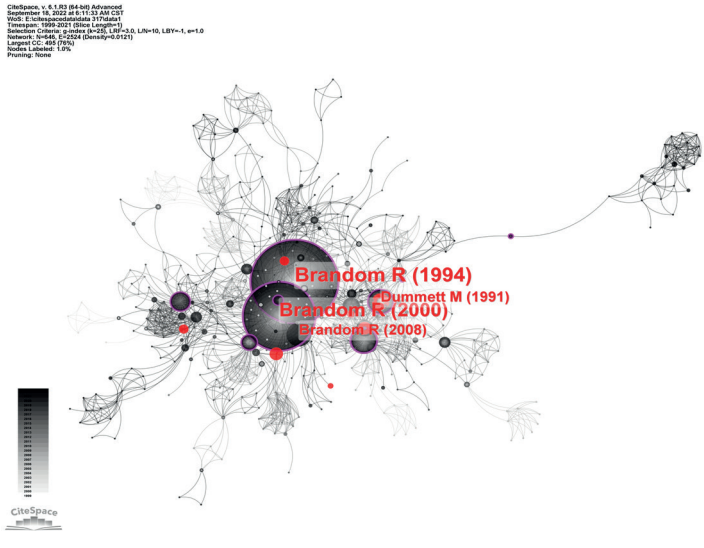


Figure 2. A 646-node co-cited references network. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyNENxUTBjTEJmTE5icndwZllEYVF5UT09&title=Yali%20Zuo's%20pictures%20)

Figure 2 shows an overview of the co-cited-references network without global pruning, which is a connected graph with color-coded links and tree-ring nodes. All nodes distributed in the network are grouped automatically based on citing articles. The time color bar is in the bottom left corner of Figure 2, and it gradually changes from down to up, corresponding to the time from 1999 to 2021. The legend color can be toggled in CiteSpace. In Figure 2, the lightest color at the bottom of the color bar indicates 1999, and the darkest color at the top indicates 2021. Each node presents a cited reference that is labeled with the author and publication year, such as Brandom R. (1994). The size of each node and label font is proportional to the citations of the reference. CiteSpace focuses on nodes that play critical roles in the evolution of a network over time (Chen et al. 2010). Salient nodes such as (1) landmark, (2) hub, and (3) pivot nodes (Chen 2004) are identified and marked after most cited documents citations counting, burst detection, centrality and sigma computation in the network.

A purple ring to a node indicates the central-pivot position of the node in terms of betweenness centrality, the value of which is no less than 0.1 and the thickness of the ring is proportional to its centrality value. A red ring to a node indicates that the node has citation burst. That is to say, citations of the node suddenly change in the corresponding time slice, indicating sharp increases of interest in some specialty or new research fronts. The nodes having a higher sigma is up to whether it is strong in both centrality and burst. The color of links presents the year in which the co-cited relationship first occurred. The thickness of a link is proportional to the strength of co-citation (Chen et al. 2010). The more colorful links a node connects, the more pivotal role the node plays between clusters or network patches.

There are four nodes labeled with different sizes of font in Figure 2, and they are in the center of the network. The node Brandom R. (1994), labeled with the largest size of font, the largest radius and purple ring, presents Brandom's work published in 1994, which is the landmark and the pivot in this field. The node labeled with the second-largest font, Brandom R. (2000), and the second-largest radius, but the largest thickness of purple ring, presents Brandom's work published in 2000 and has the strongest centrality. Dummett M. (1991) has both a purple ring and a red ring. The node labeled with Brandom R. (2008), marked with no purple ring or red ring, is strong in degree. All node labels can be displayed by lowering the citation threshold to 0, including the nodes with both purple ring and red ring or one of them, or neither of them. More information about all nodes is in the network summary table including frequency (total citations), burst, degree, centrality, sigma, author, publication year, source, volume, page, doi, half-life and cluster. Table 2 lists the top ten of references ranked by counts, degree, centrality and sigma, including 7 burst nodes.

Table 2. References, counts, degree, centrality, sigma and burst of salient nodes

References	Counts	Burst	Degree	Centrality	Sigma	ClusterID
Brandom R. (1994) *Making It Explicit*	144		48	0.27	1	2
Brandom R. (2000) *Articulating Reasons*	106		76	0.36	1	2
Brandom R. (2008) *Between Saying and Doing*	32		20	0.07	1	16
Dummett M. (1991) *The Logical Basis of Metaphysics*	30	4.11	60	0.16	1.83	0
Belnap N. (1962) "Tonk, Plonk and Plink"	24		63	0.22	1	0
Bakker A. (2011) "Lessons from Inferentialism for Statistics Education"	22		46	0.11	1	1
Prior A. (1960) "The Runabout Inference-Ticket"	21	4.34	45	0.08	1.41	0
Prawitz D. (1965) *Natural Deduction*	21		42	0.07	1	0
Peregrin J. (2014) *Inferentialism: Why Rules Matter*	19	4.29	11	0.02	1.08	5
Brandom R. (2002) *Tales Mighty Dead*	17		35	0.14	1	5
Price H. (2013) *Expressivism, Pragmatism and Representationalism*	14	3.62	21	0.04	1.15	3
Bakhurst D. (2011) *The Formation of Reason*	13		28	0.06	1	1
McDowell J. (1994) *Mind and World*	12	3.24	22	0.02	1.07	1
Brandom R. (2007) *Inferentialism and Some of Its Challenges*	11		18	0.09	1	12
Gentzen G. (1935) "Untersuchungen über das logische Schließen I"	10		27	0.17	1	0
Tennant N. (1997) *The Taming of the True*	8	3.72	16	0.01	1.04	0
Wittgenstein L. (1953) *Philosophical Investigations*	7	3.23	1	0	1	10
Williamson T. (2000) *Knowledge and its Limit*s	5		12	0.11	1	0

Table 2. References… (cont.)

References	Counts	Burst	Degree	Centrality	Sigma	ClusterID
Dancy J. (2004) *Ethics without Principles*	4		2	0.1	1	7
Cohen S. (1984) "Justification and Truth"	2		5	0.1	1	7

Source: CiteSpace 6.1.R3.

Table 2 shows twenty nodes with different properties. For instance, Brandom's work *Making It Explicit*, published in 1994 with an extraordinary value of 144, is the top item ranked by citation counts, and the second top item ranked by centrality with centrality of 0.26, but not a burst node. Michael Dummett's work *The Logical Basis of Metaphysics*, published in 1991, is strong in every variable. Neil Tennant's work *The Taming of the True* is a burst node with the value of 3.72, but weak in other variables, such as Ludwig Wittgenstein's work *Philosophical Investigations*. Tim Williamson's *Knowledge and its Limits*, Jonathan Dancy's *Ethics without Principles*, and Steward Cohen's "Justification and Truth" are only strong in centrality over 0.1. All nodes are distributed in different clusters such as #0 containing seven nodes, #1 containing three nodes, #2, #5 and #7 all containing two nodes, #3, #10, #12 and #16 both containing one node. In seven burst nodes, one node with a centrality over 0.1 is at the top ranked by sigma and the other six nodes have a centrality value below 0.1. More information on burst nodes is shown in Table 3.

Table 3 shows five burst references published in the 20th century and two burst references published in the 2[1st] century, with information about their centrality, burst, publish year, burst begin, burst end, span, waiting time and half-life. Time span is from burst begin to burst end. Waiting time is from the publication year to burst-begin. Half-life is used to characterize classic articles with persistently high citations and transient articles with their citations peak in a short period. Wittgenstein's work *Philosophical Investigations* began burst in 2019 and ended burst in 2021, with the longest half-life of 66. Arthur Prior's work "The Runabout Inference-Ticket" had the second-largest burst value of 4.28 and the second-longest half-life of 54, bursting span from 2014 to 2016. Dummett's work *The Logical Basis of Metaphysics* and Tennant's work *The Taming of the True* both began burst in 2013 and ended burst in 2015 and 2016. The other three references: John McDowell's *Mind and World*, Huw Price's *Expressivism, Pragmatism and Representationalism* and Jaroslav Peregrin's *Inferentialism: Why Rules Matter* began burst after 2015 and both ended burst in 2021, among which Peregrin (2014) has the longest span-time of 6 and the largest burst value of 4.29. The details of each node, such as citation history, citing articles and its neighboring documents in references, can be shown in CiteSpace.

Table 3. References with citation bursts

References	Centrality	Burst	Publication Year	Burst Begin	Burst End	Span	Waiting Time	Half-life
Wittgenstein L. (1953) *Philosophical Investigations*	0.00	3.27	1953	2019	2021	3	66.5	66
Prior A. (1960) "The Runabout Inference-Ticket"	0.06	4.28	1960	2014	2016	3	54.5	54
Dummett M. (1991) *The Logical Basis of Metaphysics*	0.16	4.11	1991	2013	2016	4	23.5	22
McDowell J. (1994) *Mind and World*	0.02	3.24	1994	2017	2021	5	24.5	23
Tennant N. (1997) *The Taming of the True*	0.01	3.72	1997	2013	2015	3	16.5	16
Price H. (2013) *Expressivism, Pragmatism and Representationalism*	0.04	3.74	2013	2018	2021	4	7.5	5
Peregrin J. (2014) *Inferentialism: Why Rules Matter*	0.02	4.29	2014	2016	2021	6	3.5	2

Source: CiteSpace 6.1.R3.

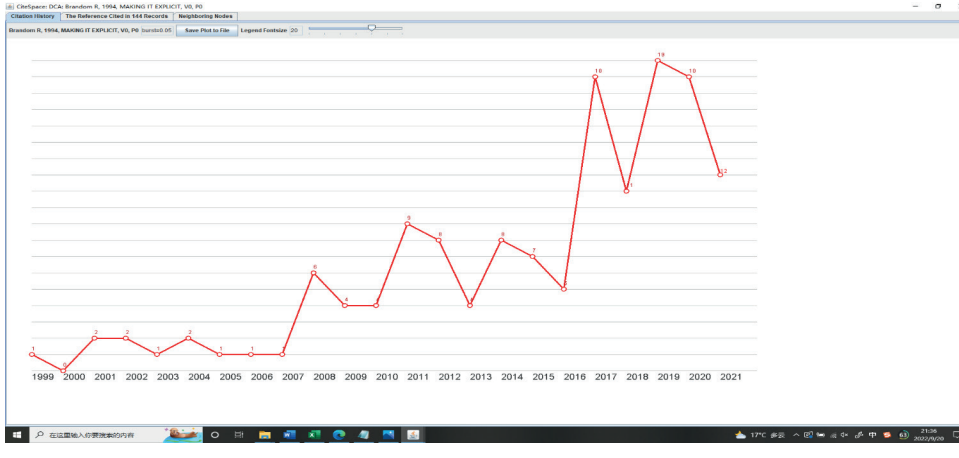


Figure 3. Citation history of Brandom (1994). Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyeVZUS0xxUEMwaXFjN1JRbnNDQTBiZz09&title=Yali%20Zuo's%20pictures%20)

Figure 3 shows the citation-history diagram of the Brandom's work *Making It Explicit*, which displays how much the book is cited in each year (particularly, the period of a burst node, which is shown by thicker red lines). The citation-history

diagram reveals that citation times for *Making It Explicit* are generally on the rise. In the duration from 1999 to 2007, the number of citations is less than 5, between 4 and 10 in the duration from 2008 to 2016, and over 11 from 2017 to 2021. It indicates that *Making It Explicit* has attracted the attention of more and more researchers. The details of who cited it and where to be cited can refer to citing-articles table and neighboring nodes.

When clicking 'The Reference cited in 144 Records' and 'Neighboring Nodes', the citing-articles table and the neighboring nodes table will appear. The information of the 144 citing articles and neighboring references are listed in the tables. After clicking on each row where a citing article is located, more details of the citing article, such as the title, descriptor terms, abstract, cited references and so on, are displayed in the lower part of the table. That is to say, each cited document, its citing article and neighboring documents can be analyzed deeply and widely according to a researcher's needs.

We not only expect to see the trees, but also see the forest. We naturally put these nodes back into the network to see what specific roles they play. We will focus on an overview of the network with clusters algorithmically generated by CiteSpace and then discuss the top largest clusters in detail by analyzing the most cited references and the major citing articles.

Clustering

A co-citation network is partitioned into a number of non-overlapping clusters with automatic cluster labeling in CiteSpace. An overview of the cluster-labeled network can be displayed by a landscape view and timeline view to highlight the characteristics of the network.

Landscape view

The relationship between clusters is visualized as the spatial layout of landscape view, as Figure 4 shows.

Figure 4 shows a topological transformation and toggled color legend of the original network with eighteen clusters algorithmically labeled. Clusters are numbered from #0 onwards with size in descending order. Each cluster is labeled based on title terms, keywords, and abstract of citing articles to the cluster, and the labels are selected by three ranking algorithms Latent Semantic Indexing (LSI), Log-Likehood Ratio (LLR) Test, and Mutual Information (MI) (Chen et al. 2010). LSI emphasizes research themes, while LLR and MI emphasize research characteristics. The clusters in Figure 4 are labeled with terms selected by LLR. The areas

of different colors indicate the time when co-citation links in those areas appeared for the first time (Chen 2017). The overlapping polygons suggest that the spatial layout and the membership of clusters still contain a considerable amount of uncertainty (Chen 2013). Some references on the boundaries of clusters are the intellectual base of different clusters.

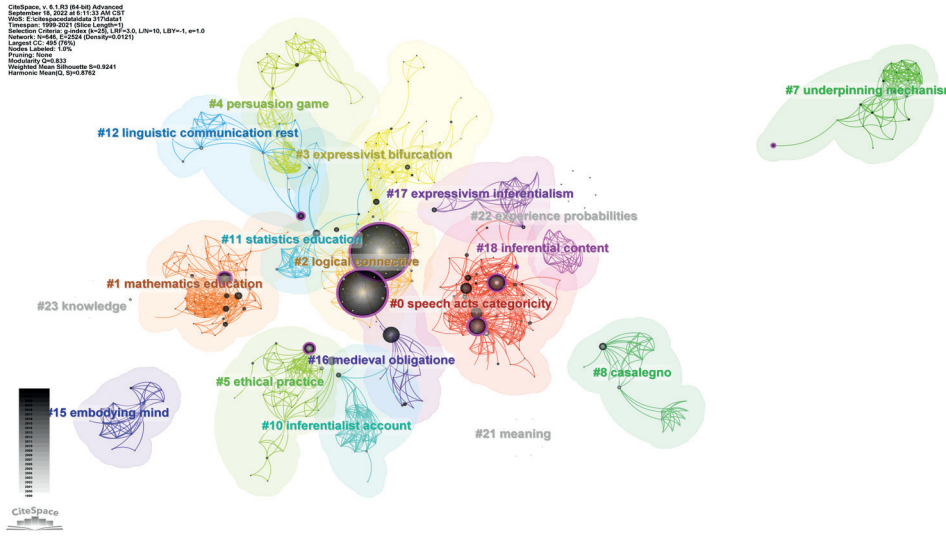


Figure 4. An overview of cluster-labeled network. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAycGFKVGRueU1IWUdzN2FSTHpheHJhZz09&title=Yali%20Zuo's%20pictures%20)

The configuration of parameters for the merged network is shown in the upper left corner. Modularity and silhouette are two parameters to measure whether the network partition is significant and whether the cluster is homogeneous. The modularity score ranges from 0 to 1. A low modularity indicates that a network cannot be reduced to clusters with clear boundaries, while a high modularity may imply a well-structured network (Chen et al. 2010). The silhouette score ranges from -1 to 1. The closer the silhouette value gets to 1, the more homogenous a cluster is, and the closer it gets to -1, the more heterogeneous a cluster is (Chen et al. 2012). The network has a modularity Q of 0.833, which is so high that the clustering structure of the network is significant. The mean silhouette S of 0.9241 is very high, indicating a very satisfactory partition of the network.

From the landscape view, we can find out the closeness of clusters. For example, *logical connective* (#2) is at the center of the network, closer to *speech categoricity* (#0), *statistic education* (#11), *mathematics education* (#1), *medieval obligations* (#16), *ethical practice* (#5), *expressivism inferentialism* (#17) and *expressivist bifurcation* (#3) than other clusters.

Timeline view

A timeline visualization depicts clusters along horizontal timelines (Figure 5). It is also useful to identify the nature of clusters and their interrelationship (Chen et al. 2010), especially the temporal properties.

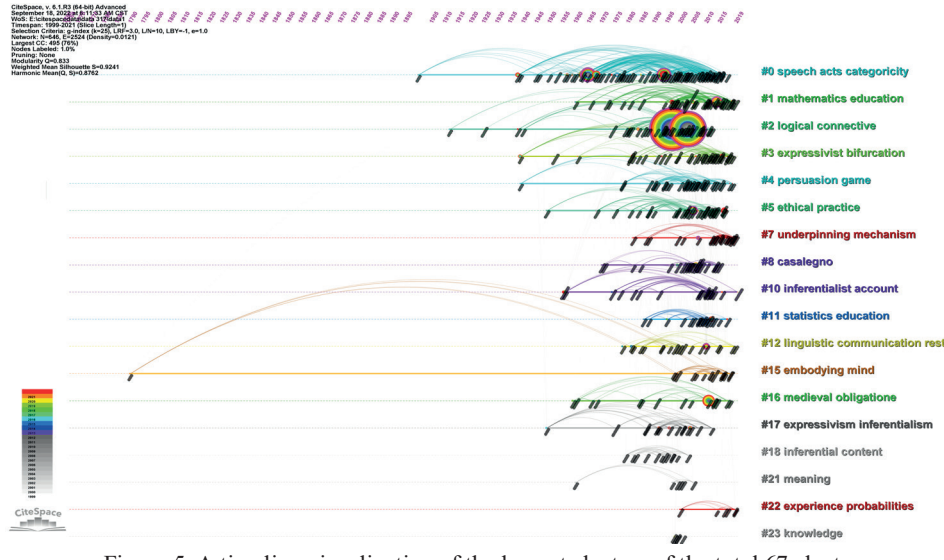


Figure 5. A timeline visualization of the largest clusters of the total 67 clusters.
Source: CiteSpace 6.1. R3
(https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAydU9sYUFlc3lkRUg3andDbXdMM0RTUT09&title=Yali%20Zuo's%20pictures%20)

The legend of the publication time is shown on top of the view (Figure 5). The length of each line represents the length of the corresponding cluster's history. Each cluster is displayed from left to right. The clusters are arranged vertically in descending order of their size. The largest cluster is shown at the top of the view. Large-sized nodes or nodes with red or purple rings are outstanding on the timeline in the clusters. The outstanding nodes on the timeline with large size would identify a high-impact specialty, whereas the red burst ring would highlight emerging specialties. The colored curves represent co-citation links added in the year of the corresponding color. The relationship of the clusters can be displayed year by year. Below each timeline, the three most cited references in a particular year are displayed. The label of the most cited reference is placed at the lowest position. References published in the same year are placed so that the less-cited references are shifted to the left (Chen 2017).

Some details of the eighteen largest clusters are listed in Table 4, including label, size, silhouette, average year and temporal properties. The labels of clusters

make some sense of the intellectual base and research front. It is up to how much and how deep the researcher understands and knows this field.

Table 4. The summary of 18 largest clusters

ClusterID	Size	Silhouette	Average Year	From	To	Duration	Top Terms (LLR)
0	92	0.796	1988	1837	2015	179	speech acts categoricity
1	52	0.935	2001	1957	2018	62	mathematics education
2	49	0.935	1989	1909	2009	101	logical connective
3	47	0.863	2000	1936	2017	72	expressivist bifurcation
4	38	0.979	1998	1936	2017	72	persuasion game
5	37	0.97	1998	1946	2014	69	ethical practice
7	24	0.982	2008	1979	2018	40	underpinning mechanism
8	23	0.989	1998	1967	2012	56	Casalegno
10	20	0.985	1995	1953	2019	67	inferentialist account
11	19	0.966	2003	1983	2015	33	statistics education
12	19	0.979	1996	1975	2018	44	linguistic communication rest
15	16	0.987	1993	1787	2016	230	embodying mind
16	15	0.937	1990	1956	2016	61	medieval obligations
17	15	0.973	1990	1946	2009	64	expressivism inferentialism
18	12	0.98	1988	1976	2000	25	inferential content
21	6	1	1990	1957	2002	46	Meaning
22	6	0.998	2012	1997	2018	22	experience probabilities
23	5	0.996	1996	1995	1998	4	Knowledge

Source: CiteSpace 6.1.R.3.

In Table 4, the largest cluster *speech acts categoricity* (#0) containing 92 references has the lowest silhouette value of 0.796 among the major clusters, but it is considered highly homogenous over 0.7. The average year of publication of a cluster indicates its recentness (Chen et al. 2012). The duration of a cluster is equal to the year of publication of the latest citation minus the year of publication of the earliest citation and then plus 1. The largest cluster #0 *speech acts categoricity* is across a 179 years from 1837 to 2015, in which the average year of all references is 1988, but the average year of the 21 most representative citing articles is 2016. Cluster *speech acts categoricity* (#0) is considered to be still active.

The most representative citing articles are automatically selected by CiteSpace. Temporal properties of major citing articles to clusters are shown in Table 5.

Table 5. Temporal properties of major citing articles to the top six large clusters

ClusterID	Size	Average Year	From	To	Top Terms (LLR)
0	21	2016	2008	2021	speech acts categoricity
1	11	2017	2011	2020	mathematics education
2	44	2015	2001	2021	logical connective
3	10	2017	2009	2021	expressivist bifurcation
4	3	2010	2006	2015	persuasion game
5	10	2015	2008	2020	ethical practice

Source: CiteSpace 6.1. R3.

The cluster with the largest size of 44 of representative citing articles is *logical connective* (#2), followed by *speech acts categoricity* (#0) with size of 21. The clusters ranked by recentness are *mathematics education* (#1) and cluster *expressivist bifurcation* (#3) with an average year of 2017, *speech acts categoricity* (#0) with an average year of 2016, *logical connective* (#2) and *ethical practice* (#5) both with an average year of 2015, *persuasion game* (#4) with an average year of 2010 and size of 3, which will not be analyzed here.

Particularly, how clusters are connected year by year can be displayed by co-citation links appearing in that corresponding year in landscape view or timeline view. Figure 6 shows the connection of clusters in 2020 in the timeline view. In 2020, co-citation links join *mathematics education* (#1) and other clusters such as *ethical practice* (#5) and *education* (#15). The co-cited references can be visualized in red font after clicking the node when needed. For example, the references co-cited with Jan Derry (2017) in *mathematics education* (#1) can be checked easily.

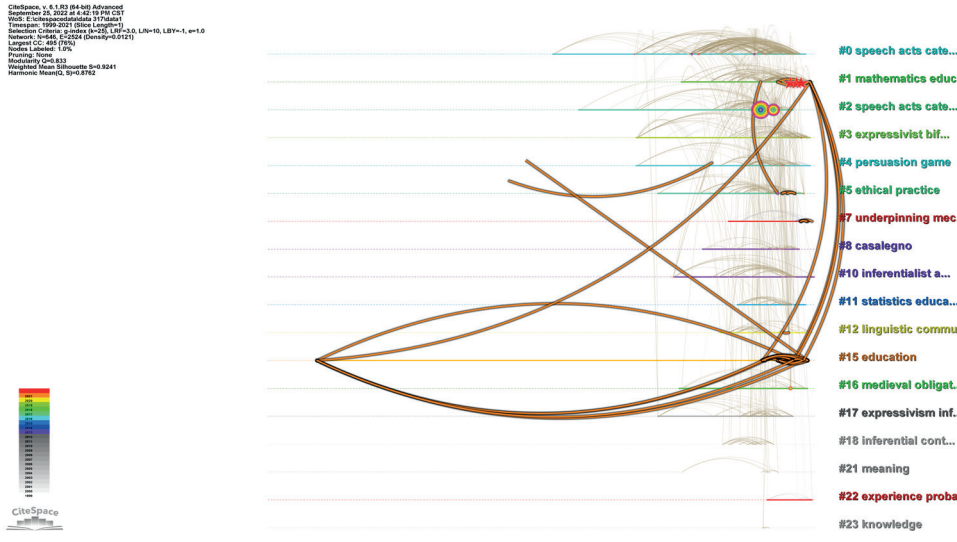


Figure 6. Connections of clusters in 2020. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyb1IxT1lCRWtmbytJeHYwdFVscXZqUT09&title=Yali%20Zuo's%20pictures%20)

All the connections are listed in Table 6.

The associations between clusters over time and the evolution of research over time are shown in Table 6. All the relationships between clusters are visualized as the spatial layout of the landscape view. From the vertical, researchers can make sense of the associations between clusters over time. For example, cluster *speech acts categories* (#0) is connected with the other sixteen clusters except for *education* (#15), and has the first strongest correlation with cluster *logical connective* (#2) in 1999, 2003, 2007, 2010, 2011, 2015, 2016, 2019 and 2021, the second-strongest correlation with *medieval obligations* (#16) in 2011, 2016, 2019, cluster *expressivist bifurcation* (#3) in 2015, 2018 and 2019, cluster *education* (#5) in 2009, 2016, and 2019, and *linguistic communication rest* (#12) in 2016, 2018 and 2019. Cluster *speech acts categories* (#0) is the most active in 2019, co-cited with other clusters. From the horizontal, researchers can make sense of the evolution of the intellectual base and research front over time, for instance, it contains *speech acts categories* (#0) and *logical connective* (#2) at least in 1999 and eleven clusters at least in 2021. Five clusters (#0, #1, #2, #3 and #5) appear more from 1999 to 2021. Clusters transit from *speech acts categories* (#0) and *logical connective* (#2) to *mathematics education* (#1), *expressivist bifurcation* (#3) and *education* (#5), from linguistic to education and expressivism. In addition, the five clusters contain fifteen salient nodes in Table 2. The following will focus on the analysis of the largest top five clusters (#0, #1, #2, #3 and #5) to explore the development of the intellectual base and research front.

Table 6. Connections of clusters year by year. Own elaboration

year\cluster	0	1	2	3	4	5	7	8	10	11	12	15	16	17	18	21	22	23
1999	2				0													
2001	18		5			2									0			
2002																		
2003	2		0															
2004	21															0		
2006			4		2													
2007	2		0															
2008	8,17		5			2		0						0				
2009	2,5		0,5			0,2												
2010	2		0,3,16	2,17		16							2,5	3				
2011	16		11,16							2			0,2					
2012			10						2									
2013		2,12	1								1							
2014				5		3												
2015	2, 3, 17	2	0, 3	0,2,4	3							2		0				
2016	2,5,12,16		0,12,16			0					0,2		0,2					
2017	8,11	2,11	1					0		0,1								
2018	3,12	0,3,5,11,16	3,5	0,2,5,12		1,2,3				1	0,3		1					
2019	1,2,3,5,10,12,16	0,5,10,12,23	0,12	0	0	0,1, 16			0,1,12		0,1,2,10		0,5					0
2020		5,15				1						1						
2021	2,7,11,22		0,3,10,11,12,17	2,12,17	16		0		3	0,2,3,12	2,3,11,17		4	2,3,12			0	

Analysis of five major clusters

The analysis of each cluster focuses on the most cited references in the cluster and the major citing articles to the cluster to identify the intellectual basis and the research front. Cited references are as the intellectual base and the citing articles are as the research front.

1. Cluster #0 speech acts categoricity

The largest cluster #0 *speech acts categoricity* contains 92 references. There are seven salient nodes in cluster #0, including three burst nodes, as Table 7 shows ranked by frequency (times cited).

Table 7. Most cited references in #0

References	Frequency	Burst	Degree	Centrality	Sigma	Cluster
Dummett (1991) *The Logical Basis of Metaphysic*s	30	4.11	60	0.16	1.83	0
Belnap (1962) "Tonk, Plonk and Plink"	24		63	0.22	1	0
Prior (1960) "The Runabout Inference--Ticket"	21	4.28	43	0.06	1.26	0
Prawitz (1965) *Natural Deduct*ion	21		42	0.07	1	0
Gentzen (1935) "Untersuchungen über das logische Schließen I"	10		27	0.07	1	0
Tennant (1997) *The Taming of the True*	8	3.72	18	0.01	1.03	0
Williamson (2000) *Knowledge and its Limit*s	5		12	0.11	1	0

Source: CiteSpace 6.1.R3.

We can get a rough idea of how the references are related in terms of publication time. The timeline visualization reveals three periods of its development (Figure 7). The first period is from 1897 to 1959. Michel Bréal's *Essai de sémantique*, the earliest reference in *speech acts categories* (#0), as a monograph on semantics, introduced a new terminology into linguistics, semantics, marking the birth of modern semantics as an independent discipline. Gerhard Gentzen's "Untersuchungen über das logische Schließen I" with degree 27 in the top ten references ranked by degree preluded the subsequent wave of high-impact studies appearing in the following periods, which broke away from the traditional formulations of predicate logic, as developed by Gottlob Frege, Bertrand Russell and David Hilbert, and introduced two new versions of predicate logic now called the N-systems and the

L-systems. This period belongs to the research field that aims to advance the conceptual and methodological capabilities of linguistics.

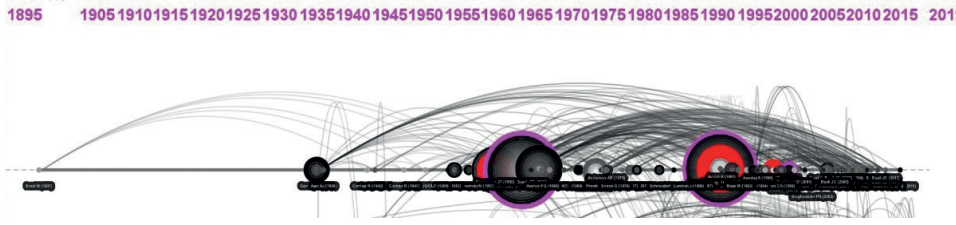


Figure 7. Key members of cluster #0. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyaTFXUjRSTUNkMEdiZy9SbXBQbFBvZz09&title=Yali%20Zuo's%20pictures%20)

The second period is from 1960 to 1990, with high-impact contributions – large citation tree-rings and citation bursts colored in red and high centrality colored in purple. Prior's "The Runabout Inference-Ticket", with a burst value of 4.28 and a centrality value of 0.06, discusses where the analytical validity of inference arises from, the meaning of certain expressions occurring in them or the meaning given by the rules, and it especially introduces the word 'tonk' to form a statement as the passage from a given statement to any other statement, not including truth tables. It explains to us how to define connectives or operations in inference. For instance, Nuel Belnap's "Tonk, Plonk and Plink", with higher centrality of 0.22 and degree of 63, emphasizes the consistency with antecedent assumptions from a synthetic, contextualist point of view. Dag Prawitz's *Natural Deduction* is perhaps the most comprehensive survey of the developments that have taken place in natural deduction up to 1965. Prawitz generalizes and extends to N-systems the results that Gentzen has established for L-systems in Gentzen's "Untersuchungen über das logische Schließen" and transfers much of Gentzen's work on successive calculus into a natural deductive framework, and covers a wide variety of topics, including the application of natural deduction to modal logic (Gentzen 1969).

The third period is from 1991 to 2015 with burst nodes and centric nodes. Dummett (1991) *the Logical Basis of Metaphysics* with high values of 4.13, 0.13, and 58 in burst, centrality and degree, comprehensively expounds the theory of meaning, truth and anti-reality and tries to extend the intuitionistic logic method applied in mathematics to the field of daily language and solve the debate between realism and anti-realism, so as to lay the logical foundation of his philosophical theory. Tennant's *The Taming of the True*, with a burst value of 3.72, defends and develops global semantic antirealism. Williamson's *Knowledge and its Limits*, with the purple ring, presents a systematic new conception of knowledge as a fundamental kind of mental state sensitive to the knower's environment. It breaks radically with the epistemological tradition of analyzing knowledge in terms of true

belief. The theory casts light on a wide variety of philosophical issues: the problem of skepticism, the nature of evidence, probability and assertion, the debate between externalist and internalist philosophies of mind, the dispute between realism and anti-realism and the paradox of the surprise examination. The arguments are illustrated by rigorous models based on epistemic logic and probability theory.

The twenty-one major citing articles convey additional information to understand the dynamics of inferentialism in the period of from 2008 to 2016, as Table 8 shows. Coverage presents how many references in the cluster are cited by the same article, revealing their similar types of contributions. For instance, coverage 22 of citing article Julien Murzi and Massimiliano Carrara's (2014) "More Reflections on Consequence" presents that there are twenty-four members of cluster *speech acts categories* (#0) among its references, including Prior (1960), Belnap (1962), Prawitz (1965), Dummett (1991), and Tennant (1997). GCS (Global Citation Score) presents the number of citations of the article in Web of Science. David Ripley's (2013) "Paradoxes and Failures of Cut" has the highest citation of 107 to #0, indicating that this topic is hot. All of them are mainly related to rules of logic and of structure (Ripley 2015), such as 'cut', 'logical connective', 'propositional logic' and 'induction', and involves logical inferentialism and semantic inferentialism, and harmony of category and proof-theoretic semantics, as Table 8 shows.

Table 8. Major citing articles to #0

Coverage	GCS	Bibliography	Year
5	107	Ripley (2013) "Paradoxes and Failures of **Cut**"	2013
11	20	Ripley (2015) "Anything Goes"	2015
14	8	Hjortland (2014) "Speech Acts, Categoricity, and the Meanings of **Logical Connectives**"	2014
11	8	Naibo (2015) "Are Uniqueness and Deducibility of Identicals the Same?"	2015
7	7	Peregrin (2008) "An Inferentialist Approach to Semantics: Time for a New Kind of **Structuralism**?"	2008
5	7	Dicher & Paoli (2021) "The Original Sin of **Proof-Theoretic Semantics**"	2010
10	7	Read (2015) "**Semantic** Pollution and Syntactic Purity"	2015
9	7	Maruyama (2016a) "Categorical Harmony and Paradoxes in **Proof-Theoretic Semantics**"	2016
12	6	Incurvati & Schlöder (2019) "Weak **Assertion**"	2019
5	6	Tranchini (2021) "**Proof-Theoretic Harmony**: Towards an Intentional Account"	2021
9	5	Maruyama (2016b) "Prior's Tonk, Notions of Logic, and Levels of Inconsistency: Vindicating the Pluralistic Unity of Science in the Light of **Categorical Logical Positivism**"	2016

Table 8. Major… (cont.)

Coverage	GCS	Bibliography	Year
7	3	Read (2016) "**Harmonic** Inferentialism and the **Logic** of Identity"	2016
5	2	Trafford (2014) "**Compositionality** and Modest Inferentialism"	2014
5	2	Walsh (2017) "**Categorical Harmony** and Path Induction"	2017
6	1	Cantwell (2015) "An Expressivist Bilateral Meaning-is-Use Analysis of Classical Propositional **Logic**"	2015
14	1	Trafford (2017) "Inferentialism and its Discontents"	2017
24	0	Murzi (2014) "More Reflections on **Consequence**"	2014
6	0	Trafford (2015) "Duality and Inferential **Semantics**"	2015
5	0	Nefdt (2018) "Inferentialism and **Structuralism**: a Tale of Two Theories"	2018
8	0	Stovall (2021) "Essence as a Modality a **Proof-Theoretic and Nominalist** Analysis"	2021
7	0	Tennant (2021) "What is a **Rule** of Inference?"	2021

Source: CiteSpace 6.1.R3.

2. Cluster #1 mathematics education

The second largest cluster *inferentialist alternative* (#1) contains 52 references with a silhouette value of 0.935. It is more highly homogenous than cluster #0. Its duration is 62 years from 1957 to 2018, and the average is 2001. The period from 1957 to 1993 is relatively uneventful, without high-profile references in terms of citation counts or bursts. Three salient nodes with large tree-rings, citation burst in red and centrality in purple appear in the period from 1994 to 2018. The key members of cluster #1 is visualized in the timeline (Figure 8).

Figure 8. Key members of cluster #1. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyWUg4OVhoWE1EbnhVWHRabWFTa3BjUT09&title=Yali%20Zuo's%20pictures%20)

Cluster *inferentialist alternative* (#1) began with Paul Grice's (1957) *Meaning*, which relates the primary intention of an utterer to the meaning (Grice 1957) of an utterance, and ended with Dor Abrahamson and Manu Kapur's (2018) *Reinventing Discovery Learning: a Field-Wide Research Program*, which points out

the design and facilitation of environments offer students opportunities to develop understanding and competence as well as to learn how to learn (Abrahamson & Kapur 2018).

In the duration from 1957 to 2018, John McDowell's (1994) *Mind and World*, with citation burst from 2017 to 2021, proposes an account of the relation between mind and world and constructs a minimum of empiricism (McDowell 1996). David Bakhurst's (2011) *The Formation of Reason*, as a hub node with large degree, utilizes ideas from philosopher McDowell to develop and defend a socio-historical account of the human mind. It provides the first detailed examination of the relevance of McDowell's work of the philosophy of education, and draws on a wide range of philosophical sources, including the work of 'analytic' philosophers Donald Davidson, Ian Hacking, Peter Strawson, David Wiggins, and Ludwig Wittgenstein. It considers non-traditional ideas from Russian philosophy and psychology, represented by Evald Ilyenkov and Lev Vygotsky, and discusses foundational philosophical ideas in a way that reveals their relevance to educational theory and practice. In the same year, Arthur Bakker's (2011) "Lessons from Inferentialism for Statistics Education", as a pivot node with high centrality, which is based on Brandom's inferentialism, suggests that inferentialism can serve as a valuable theoretical resource for reform efforts that advocate informal statistical inference and gives examples from two sixth-grade classes (age 11) to illustrate an inferentialist approach to teaching statistic and learning to draw informal statistical inferences while developing key concepts such as center, variation, distribution, and sample without losing sight of problem contexts (Bakker & Derry 2011).

This cluster applies inferentialism combined with knowledge from the disciplines such as philosophy, sociology or psychology to the field of education. Most cited references and major citing articles are listed in Table 9.

Table 9. Most cited references in #1 and major citing articles to #1

Cluster #1 mathematics education				
Cited References			Citing articles	
Cites	Author (year) title	Coverage	CGS	Author (year) title
22	Bakker A. (2011) "Lessons from Inferentialism for **Statistics Education**"	6	15	Marshall D. (2013) "The Implications of Robert Brandom's Inferentialism for **Intellectual History**"
13	Bakhurst D. (2011) *The Formation of Reason*	21	11	Noorloos R. (2017) "Inferentialism as an Alternative to Socioconstructivism in **Mathematics Education**"

Table 9. Most… (cont.)

Cluster #1 mathematics education				
Cited References			Citing articles	
12	McDowell J. (1994) *Mind and World*	6	8	Kent P. (2011) "**Measurement** in the Workplace: the Case of Process Improvement in Manufacturing Industry"
9	Derry J. (2017) "An Introduction to Inferentialism in **Mathematics Education**"	5	8	Bakker A. (2018) "**Discovery Learning**: Zombie, Phoenix, or Elephant?"
8	Bransen J. (2002) "Normativity as the Key to Objectivity: An Exploration of Robert Brandom's Articulating Reasons"	7	6	Schindler M. (2017) "Sixth-grade Students' Reasoning on the Order Relation of **Integers** as Influenced by Prior Experience: an Inferentialist Analysis"
7	Noorloos R (2017) "Inferentialism as an Alternative to Socioconstructivism in **Mathematics Education**"	21	5	Taylor S. D. (2017) "Mastering as an Inferentialist Alternative to the Acquisition and Participation Metaphors for **Learning**"
6	Derry J. (2013) "Can Inferentialism Contribute to **Social Epistemology**?"	7	4	Hussmann S. (2019) "Tracing Conceptual Development in **Mathematics**: Epistemology of **Webs of Reasons**"
5	Derry J. (2013) *Vygotsky: Philosophy and Education*	9	2	Radford L. (2017) "On **Inferentialism**"
5	Derry J. (2008) "Abstract Rationality in Education: **from Vygotsky to Brandom**"	7	2	De Vos M. E. (2019) "Exploring how Educators at the Workplace Inform their Judgement of Students' **Professional Performance**"
4	Sellars W. (1997) *Empiricism and the Philosophy of Mind*	9	1	Causton E. (2019) "Bringing Inferentialism to **Science Education**"
4	Lafont C. (2008) "Meaning and Interpretation: Can Brandomian Scorekeepers be Gadamerian Hermeneuts?"	8	0	Nilsson P. (2020) "A Framework for Investigating Qualities of Procedural and Conceptual Knowledge **in Mathematics** – an Inferentialist Perspective"

Source: CiteSpace 6.1.R3.

The reference Wilfrid Sellars' work *Empiricism and the Philosophy of Mind* is centered on the criticism of 'the Myth of the Given' and comprehensively presents Sellars' epistemology, philosophy of language, scientific realism and philosophy of mind. It is worth noting that Sellars' thoughts have inspired many philos-

ophers of mind in subsequent decades, including McDowell and Brandom. Four works of Derry introduce inferentialism to education and connect inferentialism with Vygotsky's thoughts. Ruben Noorloos' (2017) "Inferentialism as an Alternative to Socioconstructivism in Mathematics Education" is both in cited reference and citing articles not only as the intellectual base but also as research front. Jan Bransen's (2002) "Normativity as the Key to Objectivity: An Exploration of Robert Brandom's Articulating Reasons" and Cristina Lafont's (2008) "Meaning and Interpretation: Can Brandomian Scorekeepers be Gadamerian Hermeneuts" are about understanding and exploration of Brandom's inferentialism from different perspectives.

The presentative citing articles are about four aspects of inferentialism identified in the title terms marked bold such as the following:

(1) application in education practice

Noorloos Ruben (2017), "Inferentialism as an Alternative to Socioconstructivism in **Mathematics Education**"; Schindler Maike (2017), "Sixth-Grade Students' Reasoning on the Order Relation of Integers as Influenced by **Prior Experience**: an Inferentialist Analysis"; Nilsson Per (2020), "A Framework for Investigating Qualities of Procedural and Conceptual Knowledge **in Mathematics** – an Inferentialist Perspective"; Causton Edward (2019), "Bringing Inferentialism to **Science Education**".

(2) application in learning

Taylor Samuel D. (2017), "Mastering as an Inferentialist Alternative to the Acquisition and Participation Metaphors for **Learning**"; Bakker Arthur (2018), "**Discovery Learning**: Zombie, Phoenix, or Elephant?".

(3) application of "webs of reasons" in measurement

Kent Phillip (2011), "**Measurement in the Workplace**: the Case of Process Improvement in Manufacturing Industry"; Hussmann Stephan (2019), "**Tracing Conceptual Development in Mathematics**: Epistemology of **Webs of Reasons**";

De Vos Marlies (2019), "Exploring How Educators at the Workplace **Inform Their Judgement of Students' Professional Performance**".

(4) critical commentary on inferentialism in mathematics education and in intellectual history

Radford Luis (2017), "On **Inferentialism**"; Marshall David L. (2013), "The Implications of Robert Brandom's Inferentialism for **Intellectual History**".

3. Cluster #2 logical connective

Cluster *logical connective* (#2) is the third largest cluster with 49 cited references and a 101-year duration from 1909 to 2009. The average year of cited references is 1989, but the average year of major 44 representative citing articles is 2015. Its silhouette value is 0.935. It is labeled as *logical connective* by LLR, *semantic inferentialism* by LSI, and *knowledge* by MI.

From the timeline visualization of this cluster, the period from 1909 to 1970 contains four key nodes – Karl Aner (1909), Wittgenstein (1922), Gentzen (1935) and Carnap (1937), without high-profile references in terms of citation counts or bursts and are relatively scattered. The nodes are relatively dense and two outstanding references with purple rings in the period from 1971 to 2009 (Figure 9).

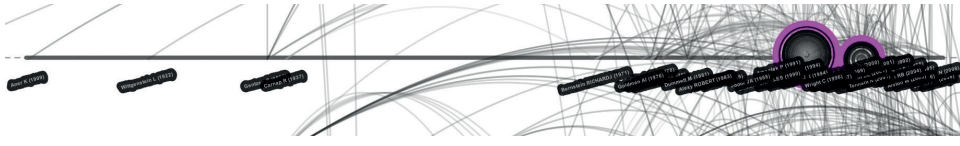


Figure 9. Key members of cluster #2. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyaVZNSWFxeHJHdEFyQzZPR3FmVDJQUT09&title=Yali%20Zuo's%20pictures%20)

Two outstanding references with high centrality are all Brandom's works. One is Brandom (1994) *Making It Explicit: Reasoning, Representing and Discursive Commitment*, the other one is Brandom (2000) *Articulating Reasons: An introduction to Inferentialism*. *Making It Explicit*, with extraordinary large tree-rings and strong centrality in purple is the landmark node, as well as *Articulating reasons: an Introduction to Inferentialism*. Both of the two books, as Brandom presents, are an investigation into the nature of language: of the social practices that distinguish us as rational, indeed logical, concept-mongering creatures knowers and agents, including criteria of adequacy for a theory of discursive practice, the approach adopted, and the model of the game of giving and asking for reasons in detail and application of the model (Brandom 1994). The first part of *Making It Explicit* is about semantic inferentialism, while the task of the second part is to reconstruct representationalism in an inferential way (Chen 2019). *Articulating reasons: An Introduction to Inferentialism* is to explain and extend some topics of *Making It Explicit*. They play the role of connecting the preceding and the following. The two books are classic literature of inferentialism research.

Table 10 shows the most cited references in #2 and the major citing articles to #2. Cited references are mainly theoretical elucidation, while citing articles contain both theoretical and practical content, including the application of inferentialism in education.

Table 10. Most cited references in #2 and major citing articles to #2

Cluster #2 logical connective				
	Cited References		Citing articles	
Cites	Author (year) title	Coverage	GCS	Bibliography
144	Brandom R. (1994) *Making It Explicit: Reasoning, Representing and Discursive Commitment*	5	21	Fodor J. & Lepore E. (2001) "Brandom's Burdens: **Compositionality** and Inferentialism"
106	Brandom R. (2000) *Articulating Reasons: An introduction to Inferentialis*m	2	19	Heusdens W. T. et al. (2016) "Contextualising **Vocational Knowledge**: a Theoretical Framework and Illustrations from **Culinary Education**"
6	Dummett M. (1978) *Truth and Other Enigma*s	4	17	Derry J. (2013) "Can Inferentialism Contribute to **Social Epistemology**?"
5	Dummett M. (1981) *Frege. Philosophy of Language*	15	12	Reiss J. (2012) *Causation in the **Sciences**: an Inferentialist Account*
5	Gentzen G. (1935) "Untersuchungen über das logische Schließen II"	2	11	Crowell S. (2008) "Phenomenological **Immanence**, **Normativity**, and Semantic **Externalism**"
4	Fodor J. (1992) *Holism: A Shopper's Guide*	8	8	Shapiro L. (2004) "Brandom on the **Normativity of Meaning**"
3	Wittgenstein L. (1922) *Tractatus Logico-Philosophicus*	3	7	Redding P. (2015) "An Hegelian Solution to a Tangle of Problems Facing Brandom's **Analytic Pragmatism**"
3	Dummett M. (1977) *Elements of Intuitionism*	2	6	Schindler M. et al. (2017) "Sixth-grade Students' Reasoning on **the Order Relation of Integers** as Influenced by Prior Experience: an Inferentialist Analysis"
2	Annis D. (1978) "A Contextualist Theory of Epistemic Justification"	17	1	Webb S. (2020) "Interpreting Kant in **Education**: Dissolving Dualisms and Embodying Mind – Introduction"
2	Brandom R. (1999) "Some Pragmatist Themes in Hegel's Idealism: Negotiation and Administration in Hegel's Account of the Structure and Content of Conceptual Norms"	15	1	de Prado Salas J. G. (2018) "**Relativism** and the **Expressivist Bifurcation**"
2	Baker C. et al. (1998) *The Berkeley FrameNet Project*	13	1	Rockmore T. (2002) "Brandom, Hegel and Inferentialism"

Source: CiteSpace 6.1.R3.

4. Cluster #3 expressivist bifurcation

Cluster *expressivist bifurcation* (#3) is the fourth-largest cluster, containing 47 members with an 82-year duration from 1936 to 2017. The average year of all references is 2001, and the average year of the 10 most representative citing articles is 2018. This cluster's silhouette is 0.89. It is labeled as *expressivist bifurcation* by both LLR and LSI, and as a *problem* by MI. The most relevant citer to the cluster is Matthew Simpson's (2018) "Solving the Problem of Creeping Minimalism". The outstanding burst node is Price's (2013) *Expressivism, Pragmatism and Representationalism* with red ring.

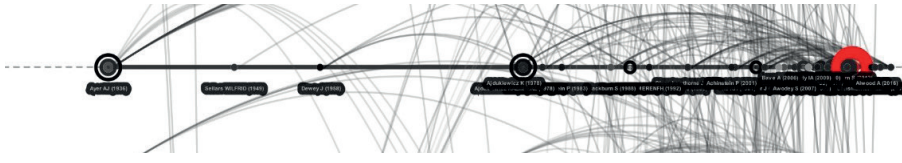


Figure 10. Key members of cluster #3. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAySU1iUksrb3VKUUk0amlZaTRPQWJKQT09&title=Yali%20Zuo's%20pictures%20)

During the period from 1936 to 1978, there are 4 key nodes in the timeline of cluster #3. Alfred J. Ayer (1936) and Kazimierz Ajdukiewicz (1978) have larger sizes than Sellars (1949) and Dewey (1958). The nodes become denser after 1978, and especially after 2004, but without high-profile references except Price (2013). We consider the most cited references in cluster #3 (Table 11) combined with timeline.

Table 11. Most cited references in #3 and major citing articles to #3

Cluster #3 expressivist bifurcation				
Cited References		Citing articles		
Cites	Author (year) title	Coverage	GCS	Author (year) title
14	Price H. (2013) *Expressivism, Pragmatism and Representationalis*m	13	7	Simpson M. (2018) "Solving the Problem of Ccreeping **Minimalism**"
10	Rorty R. (1979) *Philosophy and the Mirror of Natur*e	13	1	de Prado Salas J. G. (2018) "Relativism and the expressivist **bifurcation**"
8	Ayer A. (1936) *Language, Truth and Logi*c	10	8	Dreier J. (2018) "The **Real and the Quasi-real**: Problems of Distinction"
5	Chrisman M. (2008) "Expressivism, Inferentialism, and Saving the Debate"	7	5	Warren M. D. (2015) "**Moral Inferentialism** and the Frege-Geach Problem"

Table 11. Most… (cont.)

Cluster #3 expressivist bifurcation				
Cited References		Citing articles		
Cites	Author (year) title	Coverage	GCS	Author (year) title
5	Price H. (2011) *Naturalism Without Mirror*s	6	0	Lewis J. (2018) "**Hegel** and the ethics of **Brandom's** Metaphysics"
5	Gibbard A. (2003) *Thinking How to Live*	8	2	Carus A. W. (2018) "Going Global: Carnap's Voluntarism and Price's Expressivism"

Source: CiteSpace 6.1.R3.

Ayer's (1936) *Language, Truth and Logic* defines, explains, and argues for the verification principle of logical positivism, as it relates to the use of objectives and methods in determining truths and probabilities. Richard Rorty's (1979) *Philosophy and the Mirror of Nature* is co-cited by 10 articles in #3, which is a survey of some development in philosophy from 17th century to 20th century, especially analytic philosophy. Rorty deconstructed representationalism in a wide scope from the views of other persons such as John Locke, René Descartes, Immanuel Kant, Bertrand Russell, Edmund Husserl, Ludwig Wittgenstein, Martin Heidegger, John Dewey, Wilfrid Sellars, Willard Van Orman Quine, Donald Davison, Gilbert Ryle, John Malcolm, Thomas Kuhn and Hilary Putnam, and put the notions of "mind", "knowledge", and "philosophy" in historical perspective. He integrated and applied the milestone achievements of John Dewey, Georg W. F. Hegel and Charles Darwin in a pragmatist synthesis of historicism and naturalism. Matthew Chrisman's (2008) "Expressivism, Inferentialism, and Saving the Debate" explored what happens to that debate when taking inference rather than representation as a master concept in philosophical semantics from an inferentiallist expressivist perspective. Price's (2011) *Naturalism Without Mirrors* is a collection of fourteen essays written in about two decades from 1991 to 2010 to explore a distinctive brand of pragmatic naturalism, distinguished from popular forms of philosophical naturalism by skepticism about the centrality of representation. Price's (2013) *Expressivism, Pragmatism and Representationalism* is the most cited reference with counts of 14, which burst from 2018 to 2021. This volume includes Price's three lectures and commentary essays by Simon Blackburn, Robert Brandom, Paul Horwich, and Michael Williams. Price presented the role and significance of representationalist presuppositions in traditional forms of philosophical naturalism and contrasted his view with other contemporary forms of philosophical naturalism from different neo-pragmatist and "expressivist" programs such as Simon Blackburn, Robert Brandom, Paul Horwich, and Michael Williams. He discussed the relationship between his 'global expressivism' and the views of Sellars, and emphasized the

links of his views with those of Sellars. It is worth noting that historical perspective and synthetical perspective are prominent in the references.

The major citing articles with GCS (Global Citation Score) value of 8, 7 and 5 are: Jamie Dreier (2018) "The Real and the Quasi-Real: Problems of Distinction", Homer Simpson (2018) "Solving the Problem of Creeping Minimalism", and Mark Douglas Warren (2015) "Moral Inferentialism and the Frege-Geach Problem", which have different topics about expressivism and inferentialism. The vocabulary "problem(s)" appears in all of these titles.

5. Cluster #5 ethical practice

The 6th largest cluster *ethical practice* (#5) contains 37 cited references with a silhouette value of 0.970 and a 69-year duration from 1946 to 2014. The average year of cited references is 1998, but the average year of major 10 representative citing articles is 2015. It is considered still active. It is labeled as *ethical practice* by both LLR and LSI, and as *historical rationality* by MI.

From the timeline visualization of this cluster, the first 49-year period from 1946 to 1994 contains 7 key nodes without high-profile references in terms of citation counts or bursts. The second 20-year period from 1995 to 2014 contains 30 nodes, including two outstanding references with high centrality in purple and citation burst in red (Figure 11). Brandom's (2002) *Tales Mighty Dead* is the pivot node with high centrality and Peregrin's (2014) *Inferentialism: Why Rules Matter* is the burst node with red rings.

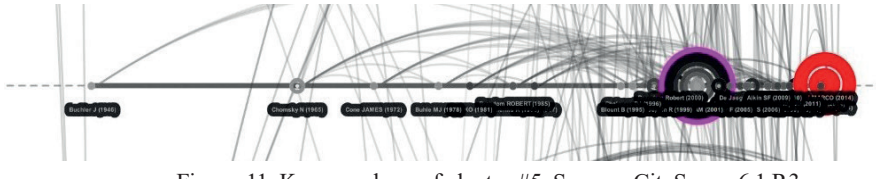


Figure 11. Key members of cluster #5. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyOGlMMDNNeUU0MFNvbjhBbVlJNVJ2QT09&title=Yali%20Zuo's%20pictures%20)

The key members of the cluster on the timeline can also provide some information on the development of the intellectual base. For example, *Philosophical Writings of Peirce* edited by Justus Buchler, as the starting point of the timeline visualization, indicates that some of the topics are related to Peirce's theory. Here, we focus on the most cited references in the cluster and the major citing articles to the cluster (Table 12), for they can cover the evolution of the intellectual base over time, to a large extent.

Table 12. Most cited references in #5 and major citing articles to #5

Cluster #5 ethical practice				
Cited References		Citing articles		
Cites	Author (year) title	Coverage	GCS	Bibliography
19	Peregrin J. (2014), *Inferentialism: Why Rules Matter*	11	13	Springs J. A. (2009), "'Dismantling the Master's House': Freedom as Ethical Practice in **Brandom and Foucault**"
17	Brandom R. (2002), *Tales Mighty Dead*	6	8	Legg C. (2008), "Making It Explicit and Clear: from "Strong" to "Hyper-" Inferentialism in **Brandom and Peirce**"
4	Redding P. (2007), *Analytic Philosophy and the Return of Hegelian Thought.*	7	3	Harrelson K. J. (2014), "Inferentialist **Philosophy of Language and the Historiography of Philosophy**"
4	Brandom R. (2000), "Facts, Norms, and Normative Facts: A Reply to Habermas"	2	2	Carus A. W. (2018), "Going Global: **Carnap's Voluntarism and Price's Expressivism**"
4	Brandom R. (2011), *Perspectives on Pragmatism*	6	1	Ocelák R. (2016), "Distribution and Inference: what **Philosophical and Computational Semantics** Can Learn From Each Other"
3	Brandom R. (2004), "From a Critique of Cognitive Internalism to a Conception of Objective Spirit: Reflections on Descombes' Anthropological Holism"	7	0	Wretzel J. (2014), "Despair and the Determinate Negation of **Brandom's Hegel**"
2	Chomsky N. (1965), *Aspects of the Theory of Syntax*	7	0	Dabay T. (2016), "Why **Peirce's Anti-intuitionism** is not Anti-**cartesian**: the Diagnosis of Pragmatist Dogma"
2	Houlgate S. (2009), "Phenomenology and De Re Interpretation: A Critique of Brandom's Reading of Hegel"	5	0	Lo Presti P. (2020), "**Individuality, Collectivity and the Intersubjective Constitution** of Intentionality"
2	McDowell J. (2010), "Brandom on Observation"	4	0	Lo Presti P. (2020), "Leave Inference alone: Direct Inferential **Social Cognition**"
2	De Jaegher H. (2010), "Can Social Interaction Constitute Social Cognition?"	2	0	Gazit Y. (2020), "Talking with Tradition: on **Brandom's Historical Rationality**"

Source: CiteSpace 6.1.R3 (with corrected bibliographic data).

The top two major citing articles (GCS>5) of the cluster are: Springs J. A. (2009), "'Dismantling the Master's House': Freedom as Ethical Practice in Brandom and Foucault", and Legg Catherina (2008), "Making It Explicit and Clear: from 'Strong' to 'Hyper-' Inferentialism in Brandom and Peirce (Robert Brandom, Charles Peirce)".

The top three most cited members in this cluster are: Peregrin (2014), *Inferentialism: Why Rules Matter*, Brandom (2002), *Tales Mighty Dead*, Redding (2007), *Analytic Philosophy and the Return of Hegelian Thought.*

Cited references are mostly related to Brandom's works, while some citing articles combine or compare different theories with each other, for instance, just from the title of citing articles, "Freedom as ethical practice in Brandom and Foucault", "From 'strong' to 'hyper' inferentialism in Brandom and Peirce", "Carnap's voluntarism and Price's expressivism", "Peirce's anti-intuitionism and Cartesian's intuitionism", and "Brandom's Hegel". It is worth noting that systematical perspective is prominent in the references as well as historical perspective and synthetical perspective in citing articles.

Remaining Clusters

The remaining clusters are either relatively small in size or short in terms of the length of their duration. A few clusters containing the salient nodes are outlined, omitting the details discussion such as cluster *underpinning mechanism* (#7), cluster *inferentialist account* (#10), cluster *linguistic communication rest* (#12) and cluster *medieval obligation* (#16).

A progressive ACA (1999–2021)

This progressive ACA is a 23-year multiple-slice analysis of all the 7501 records in types of articles and reviews. By including the top-25 most cited authors and g-index from every year between 1999 and 2021, we obtain a merged network of 555 cited authors with 2818 author co-citation links and 36 co-citation clusters. This 555-author network has a lower modularity (0.6982) than the DCA network (0.833) and a lower silhouette (0.8928) than that of the DCA network (0.9241). The ACA network has a much higher inter-cluster connectivity.

The landscape view of the co-cited author network with cluster labels automatically generated and the tree-rings nodes is shown in Figure 12. The nodes with larger size indicating that the author has more citers, or with purple ring presenting a centrality value over 0.1, or with red rings suggesting citation burst and their dis-

tribution are visualized in the landscape view. It is helpful to find out which clusters are to be focused on.

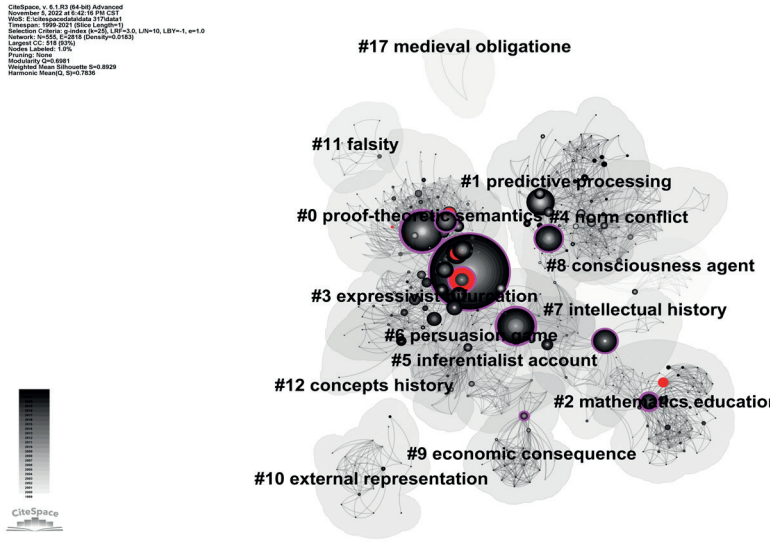


Figure 12. An overview of co-cited author network. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAycFNBSTIzZjliMXdlZi9nM2VFUjM3Zz09&title=Yali%20Zuo's%20pictures%20)

The fourteen largest ACA clusters automatically chosen labels by LLR along with their size, silhouette value and average year are listed in Table 13. Cluster *proof-theoretic semantics* (#0), containing 104 members, is the largest cluster. Its silhouette value of 0.892 over 0.7 suggests that it is a homogeneous citer set. The second-largest cluster *predictive processing* (#1) has the lowest silhouette value of 0.829, also over 0.7. That is to say, all clusters are homogeneous.

Table 13. Summary of the largest 14 clusters

ClusterID	Size	Silhouette	Label (LLR)	Average Year
0	104	0.892	proof-theoretic semantics	2010
1	69	0.829	predictive processing	2012
2	63	0.881	mathematics education	2016
3	61	0.85	expressivism bifurcation	2012
4	54	0.892	norm conflict	2010
5	33	0.894	inferentialist account	2009
6	30	0.932	persuasion game	2012
7	25	0.934	intellectual history	2009
8	22	0.971	consciousness agent	2004
9	22	0.953	economic consequence	2015

Table 13. Summary… (cont.)

ClusterID	Size	Silhouette	Label (LLR)	Average Year
10	19	0.95	external representation	2016
11	8	0.984	Falsity	2012
12	5	0.986	concepts history	2013
17	3	0.998	medieval obligations	2011

Source: CiteSpace 6.1. R3.

The top ten cited authors in each sequence are listed in Table 14. These sequences are produced in descending order of frequency, degree, centrality and sigma of the nodes in the cited-author network.

Table 14. The most cited author of the ACA network

Author	Frequency	Burst	Degree	Centrality	Sigma	HalfLife	Year	Cluster ID
Brandom Robert	195		43	0.19	1	17.5	1999	0
Dummett Michael	67		90	0.25	1	16.5	1999	0
Wittgenstein Ludwig	46	3.25	36	0.13	1.48	16.5	2002	0
Peregrin Jaroslav	40	3.7	27	0.04	1.15	7.5	2010	0
Prawitz Dag	32		51	0.05	1	6.5	2009	0
Belnap Nuel D.	28		59	0.11	1	8.5	2007	0
Prior Arthur N.	25	5.73	39	0.02	1.14	6.5	2008	0
Carnap Rudolf	20		48	0.07	1	12.5	2002	0
Tennant Neil	19	3.5	28	0.02	1.06	11.5	2003	0
Rumfitt Ian	6	3.47	16	0	1.02	0.5	2014	0
Fodor Jerry	42		36	0.07	1	15.5	2001	1
Davidson Donald	35		45	0.15	1	12.5	2004	1
Bakker Arthur	24		66	0.21	1	6.5	2011	2
Derry Jan	20	5.02	29	0.02	1.12	1.5	2017	2
Boghossian Peter	32		38	0.09	1	12.5	2006	3
Chomsky Noam	9		42	0.08	1	7.5	2001	4
Sellars Wilfrid	78		53	0.24	1	15.5	2002	5
McDowell John	45		43	0.15	1	15.5	2001	7
Canale Damiano	8		41	0.12	1	8.5	2008	9

Source: CiteSpace 6.1.R3.

The important authors are distributed in different clusters (Table 14). The ten authors including Robert Brandom, Michael Dummett, Ludwig Wittgenstein, Jaroslav Peregrin, Dag Prawitz, Nuel Belnap, Arthur Prior, Rudolf Carnap, Neil Tennant and Ian Rumfitt contribute a lot to *proof-theoretic semantics* (#0). Jerry Fodor and David Davidson are located in *predictive processing* (#1). Arthur Bakker and

Jan Derry are outstanding authors in *mathematics education* (#2). Paul Boghossian is in *expressivism bifurcation* (#3), Noam Chomsky is in norm conflict (#4), Wilfrid Sellars is in *inferentialist account* (#5), John McDowell is in *intellectual history* (#7), and Canale Damiano is in *economic consequence* (#9). They also can be identified in the timeline view (Figure 13).

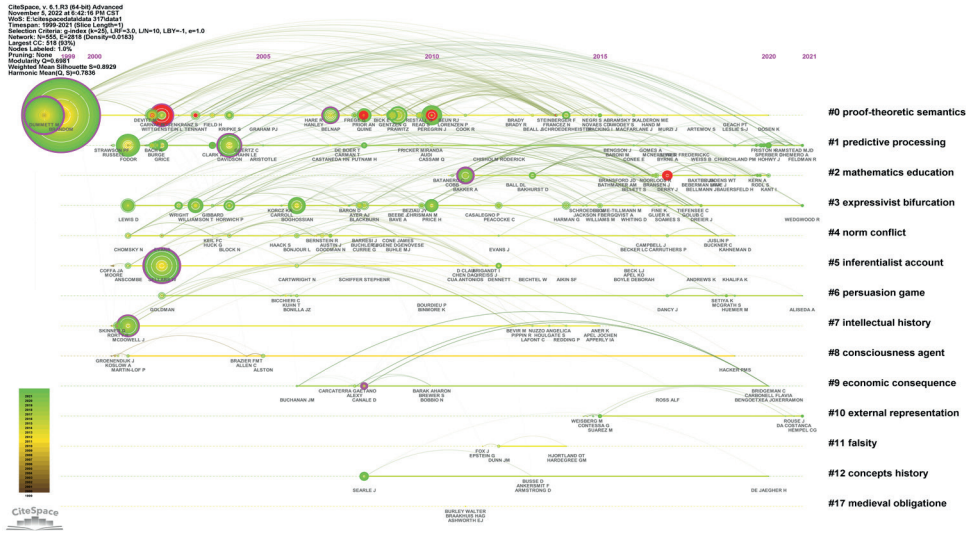


Figure 13. A timeline visualization of co-cited author network. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyWk1tN1hOa29PZTRUNlFOZ3ZZMGVGQT09&title=Yali%20Zuo's%20pictures%20)

Figure 13 shows labels of highly-cited authors in major clusters only. Different researchers may reach different insights into the nature of a co-citation cluster combined with different sources of information. It enables analysts to consider multiple aspects of the citation relationship from multiple perspectives.

Topics and disciplines co-occurrence network analysis

Co-keyword network, co-term network, co-category network and co-source network can be carried out in CiteSpace 6.1.R3 to analyze the hot topics, subject distribution and discipline structure. In all the co-occurrence networks above, nodes and links mean something similar. For example, in a co-keyword network, nodes present the keywords, and the existence of a link between two nodes (keywords) indicates that the two nodes (keywords) occur in the same document.

Co-keywords analysis

Co-keywords analysis serves to analyze the keywords provided by the authors in the data set. 'Author Keywords (DE)' and 'Keywords Plus (ID)' are two options in CiteSpace. The minimum occurrence threshold of keywords is set to 2 by frequency. The largest connected clusters of a 310-node-and-626-link keyword network are shown in Figure 14.

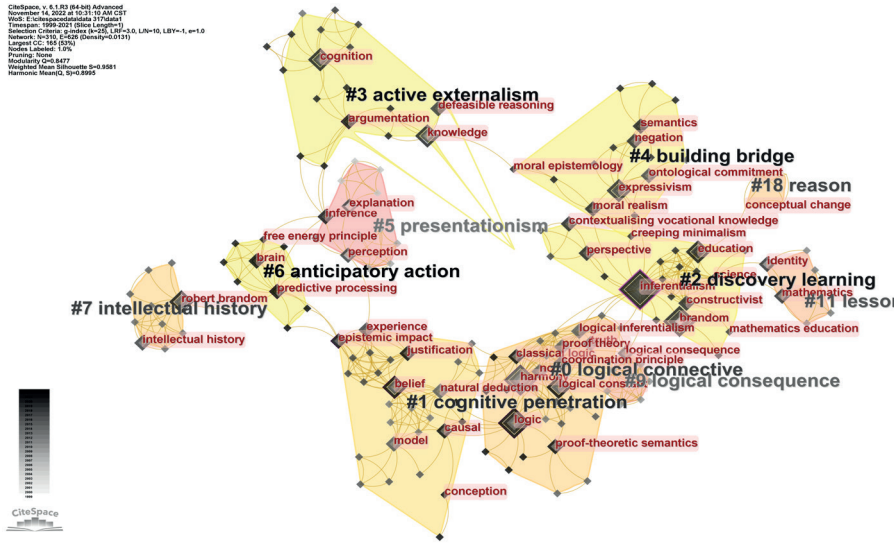


Figure 14. The largest connected clusters of a 310-keyword network. Source: CiteSpace 6.1.R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyYStReFdUVjZqZ3JuamtOSWRacXhyUT09&title=Yali%20Zuo's%20pictures%20)

The important co-occurrence keywords of the largest connected sub-network with 11-cluster labels generated automatically are visualized in Figure 14. The proximity relation between clusters is consistent with the network proximity relation of spatial view. For example, *discovering learning* (#2) is closer to *building bridge* (#4) than *reason* (#18) and *lesson* (#11) and then *logical connective* (#0), *active externalism* (#3). Cluster #0 is closer to *logical consequence* (#9) than *cognitive penetration* (#1). Cluster #1 connects to *presentationism* (#5) and *anticipatory action* (#6), and so on. All the clusters are considered highly homogenous for their silhouette over 0.7. More details of clusters are listed in Table 15.

Table 15. Summary of the 11 clusters in the sub-network of co-keyword

ClusterID	Size	Silhouette	Label (LLR)	Average Year
0	30	0.961	logical connective	2014
1	29	0.919	cognitive penetration	2014
2	21	0.96	discovery learning	2016
3	19	0.939	active externalism	2017
4	16	0.949	building bridge	2016
5	12	1	Presentationism	2006
6	10	1	anticipatory action	2020
7	10	0.995	intellectual history	2013
9	8	0.95	logical consequence	2009
11	6	0.979	Lesson	2010
18	4	1	Reason	2013

Souce: CiteSpace 6.1. R3.

The sub-co-keyword network contains six keywords with a centrality value over 0.1 and no burst items. Twenty-three nodes, which are the top ten nodes in descending order of frequency, degree and centrality, are listed in Table 16.

Table 16. Information statistic of keywords

Keyword	Frequency	Degree	Centrality
Inferentialism	11	23	0.25
Logic	8	16	0.17
Robert Brandom	6	10	0.06
predictive processing	5	12	0.12
Harmony	5	28	0.19
Expressivism	5	10	0.06
Semantics	4	7	0.02
Perception	4	9	0.07
Knowledge	4	5	0.08
Education	4	11	0.03
Cognition	4	11	0.05
Brandom	4	2	0.01
Belief	4	20	0.2
Truth	3	13	0.01
Science	3	13	0.05
moral realism	3	6	0.09
logical inferentialism	3	14	0.02
Inference	3	7	0.08
classical logic	3	16	0.05
Argumentation	3	9	0.11
No	2	14	0.01

Table 16. Summary… (cont.)

Keyword	Frequency	Degree	Centrality
logical consequence	2	13	0.01
epistemic impact	2	12	0.1

Source: CiteSpace 6.1. R3.

For example, the keyword inferentialism, with the most co-occurrence frequency of 11 and the largest centrality value of 0.25, appeared in 11 citing articles, as Figure 15 shows.

By synthesizing Figure 14 and Table 16 and reading the key literature, some research topics since the 21st century can be found from the following three aspects.

1. The application of inferentialism in education

Inferentialism as theoretical and methodological way is used to integrate minimal guidance and direct instruction for discovering learning (Bakker 2018), to trace students' conceptual development in both its individual and social facets through analyzing patterns of reasoning (Hußmann, Schacht, and Schindler 2019), to conceptualize teaching and learning from how note-taking can influence on how students come to be engaged in the language game of giving and asking for reasons in math-talk in the mathematics classroom and to investigate the possibilities to develop a teaching practice that creates synergies between talk-based teaching of mathematics and note-taking (Nilsson 2019), to explore the possibility of putting the game of giving and asking for reasons into practice by deploying two-tier multiple-choice tests for assessment of concept passion at school (Marabini & Moretti 2017), and to interpret knowledge as a capacity to engage in the particular form of social activity, the game of giving and asking for reasons, in science education (Causton 2019). Furthermore, inferentialism is applied in vocational education with complex interrelations and highly contextual practice. Conceptualizing and concretizing involves inferring, which is helpful to understand the nature of vocational knowledge and to develop vocational knowledge (Heusdens et al. 2016). Seeing assessment of workplace learning as judgment based on social interaction within a community of practice is helpful to learn how educators inform their judgment of a student involving the explicit criteria and latent criteria, and assessment of student performance in the workplace may be conceptualized as continuous progress of judgment during which educators employ a variety of strategies (De Vos et al. 2019). The above research from 2016 to 2019 mainly focuses on the application of the game of giving and asking for reasons of inferentialism.

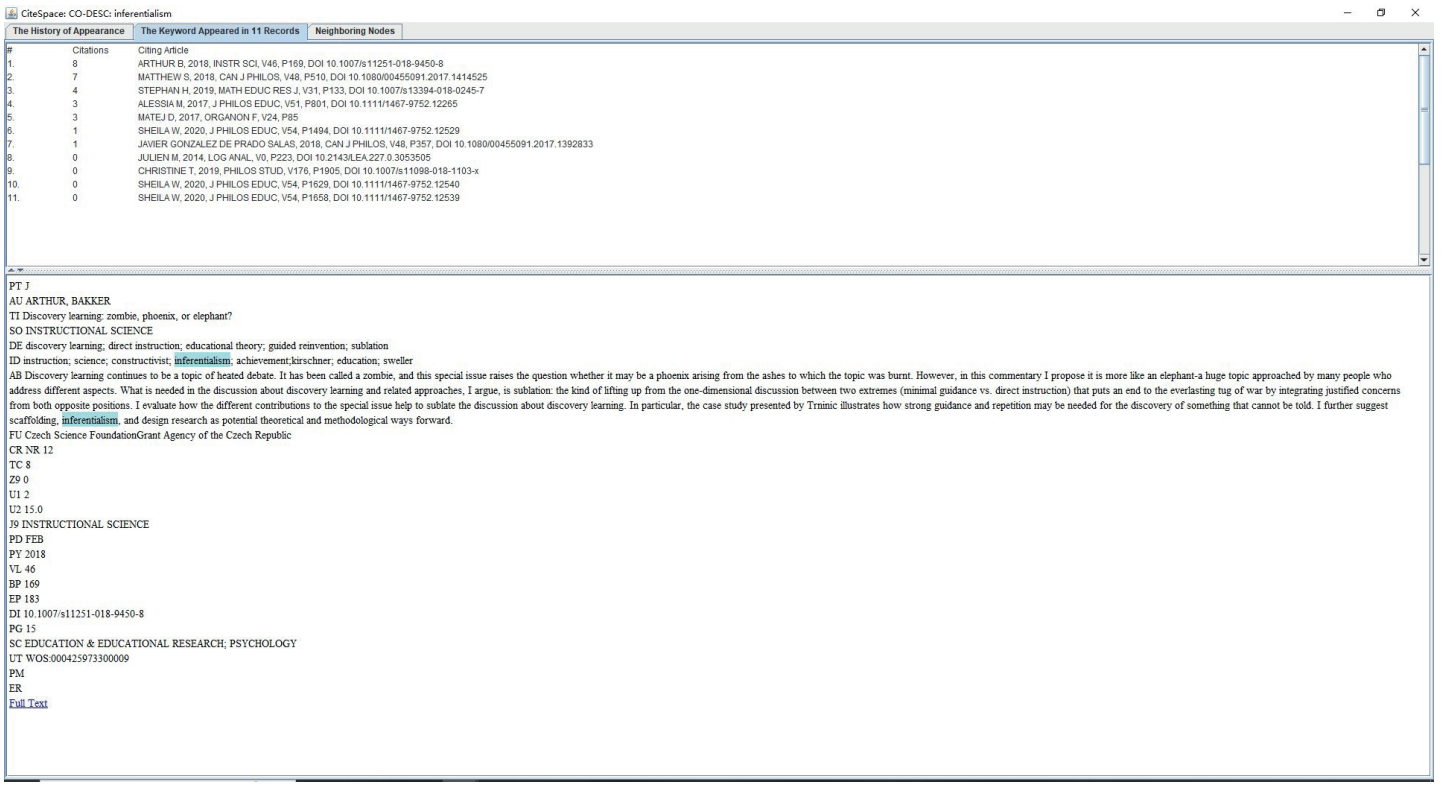


Figure 15. Citing articles of inferentialism. Source: CiteSpace 6.1. R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyT3RYK3Z2QnhkM0ZENFZiaTJjY2VTQT09&title=Yali%20Zuo's%20pictures%20)

2. The relation of inferentialism to logic, metaethics, expressivism, perception and cognition

Logical inferentialism focuses on issues of logical constants, logical connectives, logical consequences, inferential rules and logical calculi. For instance, Florian suggests logical inferentialism should reject multiple-conclusions logic (Steinberger 2011). Alberto Naibo illustrates a deep difference between two conditions used to define logical constants: Belnap's uniqueness and Hacking's deductibility of identical, which is driven by Curry-Howard correspondence (Naibo & Petrolo 2015). Ripley examines the role of structural rules in an inferentialist theory of meaning and sketches a theory in which the left and right sequent-calculus rules succeed involving connective tonk (Ripley 2015). Ole Thomassen Hjortland shows that categorical systems can be given for any finite many-valued logic using n-sided sequent calculus called multilateralism as a further development of bilateral systems, incorporating the logic of a variety of denial speech acts (Hjortland 2014). Dicher challenges two assumptions at the heart of proof-theoretic semantics. The first is that, given a derivability relation in a suitable proof system, there always *exists* a consequence relation corresponding to it. The second is that the corresponding consequence relation is *unique*, and claims two assumptions above are the *original sin* of proof-theoretic semantics by illustrating consequence relations relevant for proof-theoretic semantics is the one given by the sequent-to-sequent derivability relation in Gentzen systems (Dicher & Paoli 2021).

Inferentialism is connected to metaethics and expressivism in the debate of their distinction, such as the metaethics differences between moral realism and expressivism (Tiefensee 2016), the ways of distinguishing quasi-realism in metaethics from non-naturalist realism (Dreier 2018), the problem of creeping minimalism in distinguishing metaethical expressivism from its rivals (Simpson 2018) and in affecting error-theory's disagreement (Tiefensee 2019), and an inferential account of Frege-Geach problem (Warren 2015) as well as of ethical univocity (Warren 2018).

Inferentialism is related to perception and cognition through accounts for cognitive penetration of perception (Lyons 2016), the ability of moral perception to explain moral knowledge (Wodak 2019), and predictive processing of perception (Ghijsen 2021).

3. Robert Brandom's inferentialism and (intellectual, philosophical) history

Some citing articles concern Brandom's inferentialism and intellectual history. These are, for example, Marshall's article *The Implications of Robert Brandom's Inferentialism for Intellectual History* published in 2013 and Kevin J. Harrelson's *Inferentialist Philosophy of Language and the Historiography of Philosophy* published in 2014.

The interrelation of the keywords can be analyzed through the visualization of the timeline view (omitted here) if researchers need.

Co-term analysis

Noun phrases of co-term analysis are mainly extracted from the title (TI), author keywords (DE), keywords plus (ID) and abstract (AB). The minimum occurrence threshold of keywords is set to 14 by degree. The largest connected clusters of a 570-node-and-1721-link term network are generated. The co-term network is larger than co-keywords network, but the method of analysis is similar. From the statistic of terms (Table 18), the co-term network contains a burst node metaethics and two nodes with a centrality value over 0.1 which are inferentialism and inferentialist approach.

Table 17. Statistic of terms

Term	Frequency	Burst	Degree	Centrality	Sigma
Inferentialism	105		216	0.86	1
Robert Brandom	17		44	0.07	1
Brandom	16		43	0.1	1
logical constant	11		20	0.02	1
inferentialist account	10		19	0.1	1
Inference	10		20	0.06	1
Expressivism	10		26	0.03	1
Pragmatism	9		31	0.03	1
inferentialist approach	9		28	0.12	1
conceptual content	7		24	0.02	1
brandoms inferentialism	7		25	0.06	1
Metaethics	6	3.18	13	0.01	1.02
Dummett	3		13	0.05	1
Deflationism	3		16	0.06	1
Brandom's account	2		16	0.06	1

Source: CiteSpace 6.1. R3.

Table 18. Statistic of categories

Category	Citation Counts	Burst	Degree	Centrality	Sigma	Year	Cluster ID
PHILOSOPHY	223		20	1.19	1	1999	0
HISTORY & PHILOSOPHY OF SCIENCE	35		5	0.02	1	2001	0
EDUCATION & EDUCATIONAL RESEARCH	22	3.98	4	0.2	2.09	2001	0
COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	9		8	0.09	1	2004	0
SOCIAL SCIENCES, INTERDISCIPLINARY	8		4	0	1	2012	0
HISTORY OF SOCIAL SCIENCES	9		1	0	1	2001	1
LANGUAGE & LINGUISTICS	8		10	0.12	1	2009	1
LINGUISTICS	5		8	0.17	1	2002	1
COMPUTER SCIENCE, INFORMATION SYSTEMS	2		5	0	1	2014	1
INFORMATION SCIENCE & LIBRARY SCIENCE	1		5	0	1	2014	1
COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	1		5	0	1	2014	1
ETHICS	10		4	0.2	1	2004	2
PSYCHOLOGY, MULTIDISCIPLINARY	5		3	0.1	1	2004	2
LOGIC	29		8	0.05	1	2008	3
MATHEMATICS	13		4	0.1	1	2010	3
MATHEMATICS, APPLIED	8		4	0	1	2010	3
COMPUTER SCIENCE, THEORY & METHODS	3		5	0.01	1	2015	3

Source: CiteSpace 6.1. R3.

In addition to the parameters that can be set, co-term network analysis is most importantly related to the maturity of the field. Therefore, the interpretation of the network needs to be closely combined with the professional background. A deeper analysis is not given here.

Co-category analysis

The subject distribution and discipline structure is visualized in Figure 16.

The larger the size of a node, the more co-occurrences it has. The nodes with a centrality value over 0.1 are marked in purple, as well as the burst nodes marked in red rings. These nodes with large sizes and purple rings or red rings, such as philosophy, history & philosophy of science, education & educational research, logic, ethics, linguistics, language & linguistics, psychology multidisciplinary, and mathematics, are easily identified in the network and they form a connected subnetwork. Of course, the isolated nodes such as law, economics, nursing and geography may be connected with the largest connected sub-network in some ways.

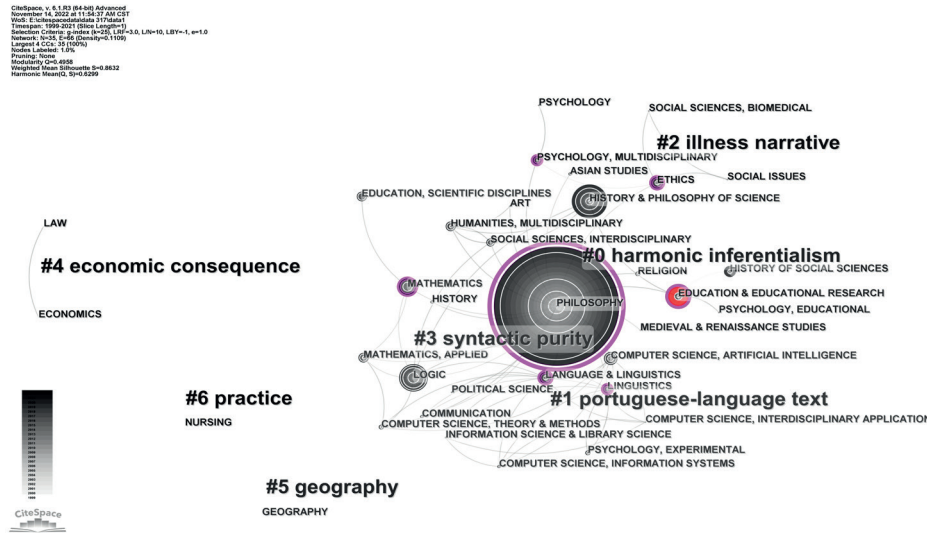


Figure 16. An overview of co-category network. Source: CiteSpace 6.1. R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAycE5xOGtQZ3hJSXpQbFJoR2RabmczQT09&title=Yali%20Zuo's%20pictures%20)

More details of seventeen categories are listed in Table 18, which are selected from the top ten in descending order of citation counts, burst, degree, centrality and sigma. The only burst subject is education & educational research, which also has a centrality value of 0.2. The most co-occurrent subject is philosophy, with extraor-

dinary citation counts of 223 and also the highest centrality value of 1.19, followed by history & philosophy of science, with citation counts of 35, and logic, with citation counts of 29. The other subjects with higher centrality value are ethics, linguistics, language & linguistics, psychology multidisciplinary, mathematics, computer science artificial intelligence.

Research collaboration network analysis

CiteSpace provides three levels of research collaboration network analysis: micro-author cooperation network, medium-institutional cooperation networks and macro-national or regional cooperation network. In a cooperative network, nodes present authors, institutions and countries/regions. If there is a link between nodes, there is a cooperative relationship between nodes. The size and color of nodes represent the number and publication time of articles published by authors, institutions and countries/regions, while the thickness and color of links represent the strength and time of mutual cooperation. Here, we omit the analysis of institutional cooperation networks and look at the collaboration between countries or regions first (Figure 17).

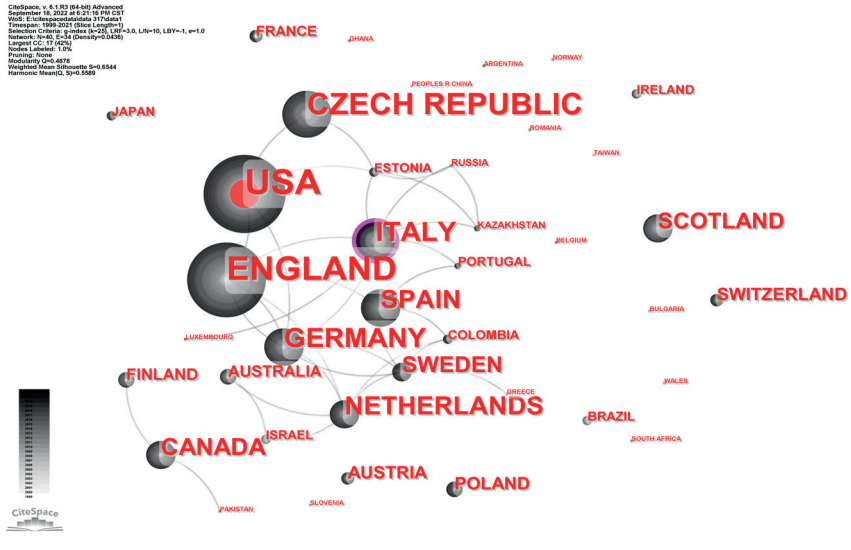


Figure 17. 40-node collaborating countries/regions network. Source: CiteSpace 6.1. R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyOC84dkZXaW9hdXozbVZwdVMydzFBUT09&title=Yali%20Zuo's%20pictures%20)

Figure 17 shows a landscape view of a 40-node-and-34-link collaborating countries/regions network. The details of each node can be checked similar to the node of the DCA network. From the visualization of the landscape view, collaboration between countries/regions is clear at a glance. Twenty countries work alone, and the other twenty countries form two sub-connected networks. One contains Finland, Canada and Pakistan; the other contains seventeen nodes, including the United States of America with citation burst in red, Italy with centrality over 0.1 in purple, England, Czech Republic, Spain, Germany and other countries shown in Figure 17. In terms of the degree of cooperation, the countries with close cooperation are mainly in Europe and America. In terms of the citation counts (Table 19), the United States of America, with 59 pieces of literature, contributes the most. It is followed by England with 48, the Czech Republic with 33, Germany with 22, Italy with 21, Spain with 18, the Netherlands with 17, Canada with 13, Sweden with 12 and Scotland with 11. In terms of centrality, Italy has the highest centrality of 0.12 over 0.1, followed by the Netherlands, Germany, England, Sweden, the USA, Spain, Estonia and Portugal.

Table 19. Statistic of countries/regions

Country	Frequency	Burst	Centrality	Degree	Sigma	Cluster
USA	59	6.12	0.04	4	1.24	2
ENGLAND	48		0.06	5	1	2
CZECH REPUBLIC	33		0	2	1	2
GERMANY	22		0.08	5	1	2
ITALY	21		0.12	7	1	1
SPAIN	18		0.02	4	1	0
NETHERLANDS	17		0.09	6	1	3
CANADA	13		0	2	1	4
SWEDEN	12		0.05	5	1	0
SCOTLAND	11		0	0	1	23
ESTONIA	3		0.02	5	1	1
PORTUGAL	3		0.01	2	1	0

Source: CiteSpace 6.1. R3.

From the timeline visualization of collaborating countries/regions network, the topic or area which each country/region focuses on is displayed as corresponding cluster labels (Figure 18).

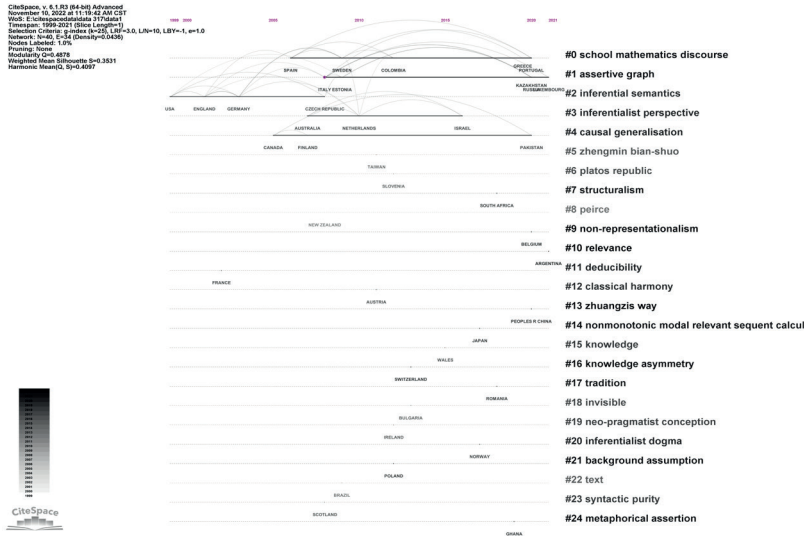


Figure 18. A timeline visualization of collaborating countries/regions network.
Source: CiteSpace 6.1. R3
(https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyWGROOHFZSzJNLzg1K1cvbDVUZVhSUT09&title=Yali%20Zuo's%20pictures%20)

The collaboration of countries/regions is mainly in areas of school mathematics discourse, assertive graphs, inferential semantics and inferentialist perspective. Other topics are showing signs of doing research alone.

About the author's cooperative network, we focus on the largest connected sub-network. A 232-node-and-66-link collaborating authors network is visualized in Figure 19. Arthur Bakker is the one who collaborates the most, followed by Jan Derry.

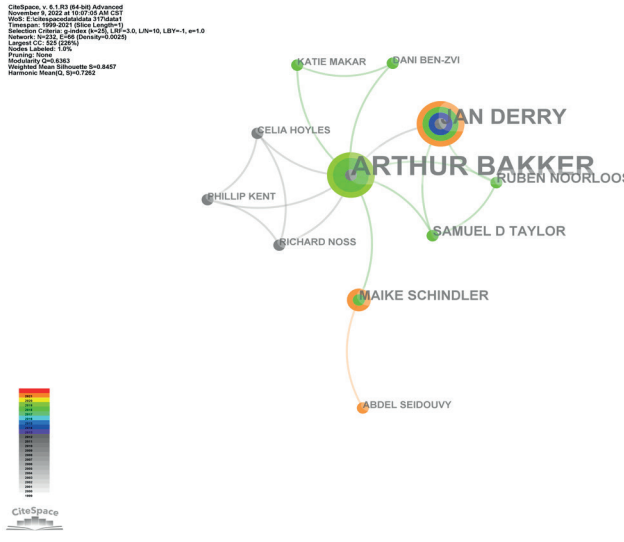


Figure 19. The largest sub-network of collaborating authors. Source: CiteSpace 6.1. R3 (https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyUXpVcXovMUZLUmI3ZEJoNWhuTm5wQT09&title=Yali%20Zuo's%20pictures%20)

The timeline visualization (Figure 20) reveals some more information about the sub-network of collaborating authors, such as the collaborating duration from 2010 to 2020 and the collaborating area in mathematics education from an inferentialist perspective.

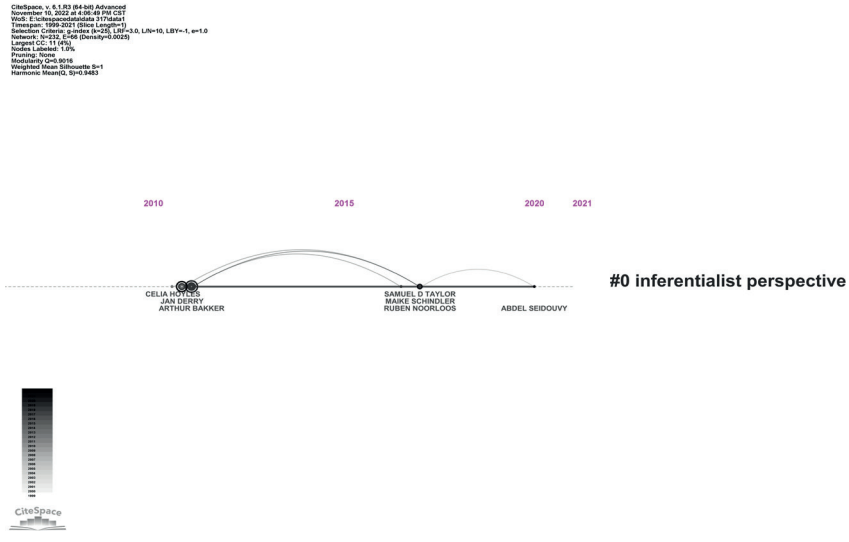


Figure 20. Key members of the largest sub-network of collaborating authors.
Source: CiteSpace 6.1. R3
(https://mail.163.com/large-attachment-download/index.html?p=X-NTES-HUGE-ATTACHMENT&file=djAyU1l6Uk9ySTVwU1dzaWYyT01hQ0d6dz09&title=Yali%20Zuo's%20pictures%20)

III. Conclusion

This article conducts a systematic review of inferentialism research by applying CiteSpace software. The procedure used in this article applies to the analysis of other domains of interest. These visual analytic tools are helpful for researchers to perform surveys of the literature timely and to find relevant publications more effectively. This survey identifies the classic literature and the major clusters in terms of high-impact members in clusters and citing articles to clusters through DCA and ACA. The landscape view and timeline view can make sense of the relationship between clusters and clusters' evolution over time, which also provides a reliable historiographic survey of inferentialism research. Topics and disciplines involved can be found through co-keyword network analysis, co-term network analysis and co-category network analysis. Different researchers can get different insights according to their needs and interests. Research collaboration network analysis can give researchers enlightenment on the level of collaboration.

Limitation

The limitation comes from the following four aspects:

A. Limitation of the quality and quantity of data

The scope of the data is limited by the source of the retrieval and the composite query used. The data for this survey is only retrieved from Web of Science and the query is only "'inferentialism' or 'inferentialist'". Iterating queries or adding other data sources can improve the quality and quantity of data.

B. Limitations of analytic methods

Citation context analysis, structural variation analysis and other additional methods may be incorporated to do a more in-depth analysis.

C. Limitation of software

This survey only uses CiteSpace which faces the literature in English mainly, and some of the pictures are not very readable. Incorporating other software may enrich the insights of researchers. In addition, software updates can cause changes in the visualization of the same data.

D. Limitation of researcher's professional level

The researcher's professional level limits the use of the software and the interpretation of the results. With the update of software and the development of field research, researchers are always on the road to learning.

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