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REVIEW

Overview of Mental Models research using bibliometric indicators

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Abstract

The Mental Model concept has evolved from being a representation of reality to which we apply formal logic, to a type of logic with which we make decisions, learn, and adapt. This work uses bibliometric indicators to describe research on Mental Models from 1997 to 2017. The results show progressive growth since the late 1990s and a stationary trend starting in 2010. The existing research is dominated by the fields of individual and organizational psychology as well as education. Since 2007, a corpus of research (works that continue or are based on previous work) has been developed around the themes of memory, cognition, interpretation, and Johnson-Laird's work. In the late 2000s, another possible corpus emerged around team work. It is recommended to develop similar research in specific areas.

Keywords Mental Model theory · Bibliometrics · Web of science · VOSviewer

Introduction

Research on Mental Models began with Craik (1943) and his idea that humans make models or analogies of real events that we then process through rules to make predictions quickly and efficiently. Mental Models are seen as a representation of a domain that supports understanding and prediction (Craik 1943; Johnson-Laird 1983). Mental Models research draws on various disciplines such as psychology, organizational theory, economics, political sciences, and system dynamics (Gary and Wood 2016).

Mental Models influence decision making and learning, e.g., text comprehension (Grenier and Dudzinska-Przesmitzki 2015; O'Brien and Albrecht 1992). Problem solving is related to Mental Models that problems evoke; with them we predict events, judge probability, and evaluate causal relationships (Kahneman and Tversky 1982; Kahneman et al. 1982). Mental Models represented by metaphors (e.g., controlled chaos or virtual reality) create specific domains of language by capturing contradictions, and they serve to explain unknown domains (Hill and Levenhagen 1995; Jones et al. 2011); when they are used and teaching, those metaphors are reified, e.g., clinical practice guidelines in hospitals (Hill and Levenhagen 1995; Hysong et al. 2018).

Evans (2006) states that the term Mental Models have been used to refer to: (a) mental simulation, i.e., a form of knowledge of elements and their causal relationships (Bagdazarov et al. 2016; Goltz and Slade 2016), e.g., the analysis of dynamic systems (Schaffernicht 2011; Scott et al. 2016); (b) semantic models, i.e., a representation of the state of the world, a type of logic with which humans make decisions (Johnson-Laird 1983; Johnson- Laird 2001; Johnson-Lairdf et al. 2015; Khemlani et al. 2017); and (c) epistemic models, i.e., in addition to the state of the world, the degree of conditional belief in the representation is denoted (Evans 2006).

Mental Models represent possibilities (each is a different set of possibilities), are iconic (the structure of model and the structure of what it represents are similar), are true (they represent only what is true, not what is false in each possibility), and are parsimonious (Johnson-Laird 2001; Khemlani et al. 2014). Mental Models has potential biases (Doyle and Ford 1999). There are three general methods of obtaining Mental Models: verbal (open or semi-structured interview),

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graphic (maps with variables and their relationships), and hybridized (a combination of verbal and graphic) (Grenier and Dudzinska-Przesmitzki 2015).

The research on Mental Models as mental simulation (Evans 2006) uses the symbolic theory, which states that knowledge is obtained by manipulating symbols through rules (Urrutia 2012). This approach does not account for people's experiences or the culture in which they are immersed (Varela et al. 1997). According to Ruiter et al. (2012), Mental Models have an incarnate (biological), transactional (medium, individual, and world interaction), and cultural nature. In terms of the Embodiment Theory, the meaning of Mental Models can be based on motor and perceptual states (Urrutia 2012); thus, they have a neural dimension that can be explored not only on an individual level (Bryce and Blown 2016) but also at the level of coworking teams, e.g., by studying the role of the Mirror Neuron System (Rizzolatti and Craighero 2004).

When people get together to execute a task, each one has their own Mental Model about what to do and how; by sharing, they may anticipate others actions and coordinate their behaviors (Burtscher and Manser 2012; Lim and Klein 2006). The Team Mental Model is a type of group cognition whose content consists of the mental representations of key elements of team processes and tasks, both positively related to team performance (Mathieu et al. 2000; Mohammed et al. 2010; Jones et al. 2011). There is no single methodology to measure Team Mental Models (Langan-Fox et al. 2000). Team Mental Models have two properties: similarity (degree to which the Mental Models of its individual members converge) and precision (degree to which the team mental model is consistent with a standard) (Mohammed et al. 2010; Burtscher and Manser 2012).

Despite the development in research of Mental Models, there is no study that measures the activity, impact and links between the various investigations (Narin et al. 1994). This work is descriptive, and its purpose is to use bibliometric indicators to give a general overview of Mental Model research from the past 40 years (the period in which almost all works on this topic have been produced), and to discern the possible future lines of development.

This article is structured as follows: in the second section, the methodology to be used is presented. In the third section, we describe the results of the most commonly used bibliometric indicators. Finally, conclusions are provided in the fourth section.

Methodology

The term "bibliometric" is attributed to Pritchard (1969) and has been defined as a discipline that quantitatively studies the bibliographic material in order to analyze an area of research through articles, journals, authors, citations, institutions, and countries (Merigo et al. 2015). Bibliometrics allows us to analyze publications not only structurally (author, title, source, year, pages) but also interactively (citations). For Bar-Ilan (2008), the research process is strengthened by continually analyzing the development of citations, the visibility of journals and institutions, and publications' impact factors.

In October 2018, a literature review was conducted in the Web of Science (WoS) database, which was selected because the scientific community considers its indices to be serious and prestigious (Andrade-Valbuena and Merigo 2018). The Web of Science database belongs to Thomson & Reuters; it includes the research of almost all known scientific fields and currently covers information from more than 15,000 journals and 50 million articles. It classifies this information into 251 thematic categories and in 151 research areas (Merigo et al. 2015).

The keywords "Mental Models" and "Mental Model" were used, filtering by article, review, and proceeding paper. The data were exported to Excel for processing (i.e., the title, authors, and sources were uniformly formatted, and incomplete data were deleted); this resulted in a database of 4805 records.

Tables with the most commonly used statistics and bibliometric indicators were then developed (Bar-Ilan 2008), i.e., the most cited publications, journals with the most publications, most published authors, h-index, impact factor, threshold of citations, total publications, total citations, and the average of citations. Citation analysis facilitates the process of sorting important articles from those that are of lesser impact (Narin et al. 1994) although the specificities of each field should be considered.

In addition, a bibliometric map (Merigo et al. 2016) was made using the VOSviewer software developed by Van Eck and Waltman (2009); the map reflects the strength of relationship. Bibliometric mapping done with VOSviewer allows us to appreciate similarities, with the size of spheres representing the number of citations, and the thickness and length of the links representing the strength of co-citations. Fractional counting is used, which is to say that the system assigns a fraction of one to each author of a given publication (Andrade-Valbuena and Merigo 2018). This method seeks to identify the bridges between the various sub-areas of research (Andrade-Valbuena and Merigo 2018).

Results

The 4805 records obtained were classified by the year in which they were published, as shown in Fig. 1. As can be observed, between 1976 and 1988, the maximum production reached nine works per year, and it is not until

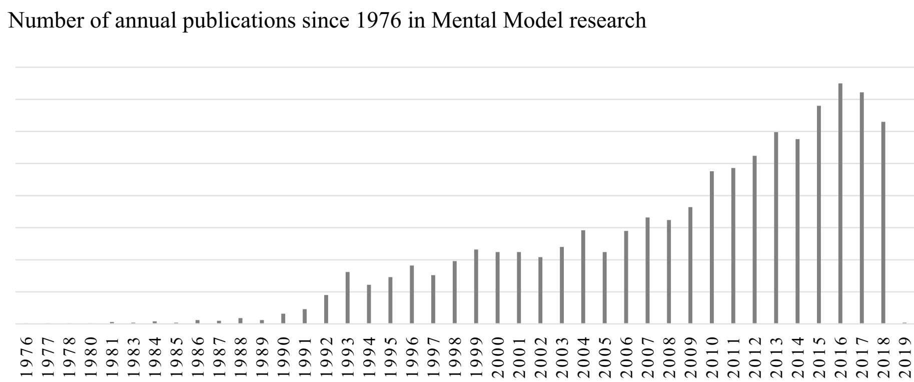

Fig. 1 Number of annual publications since 1976 in Mental Model research

Table 1 Percentage of Mental Models publications

Year	Mental models publications	Total publications	P-MM (%)
1997	76	1,160,155	0.0066
1998	98	1,162,241	0.0084
1999	116	1,188,159	0.0098
2000	112	1,205,591	0.0093
2001	112	1,192,287	0.0094
2002	104	1,234,461	0.0084
2003	120	1,270,543	0.0094
2004	146	1,357,902	0.0108
2005	112	1,436,060	0.0078
2006	145	1,502,842	0.0096
2007	166	1,574,308	0.0105
2008	162	1,661,187	0.0098
2009	182	1,735,538	0.0105
2010	238	1,778,023	0.0134
2011	243	1,861,350	0.0131
2012	262	1,942,418	0.0135
2013	299	2,036,295	0.0147
2014	288	2,087,895	0.0138
2015	340	2,431,865	0.0140
2016	375	2,536,261	0.0148
2017	361	2,593,380	0.0139
Total	4057	34,948,761	0.0116

1998 that 98 publications per year are achieved. In 2007, 166 works are retrieved, and finally in 2016, 375 publications are made. In order to concentrate the useful information for bibliometric analysis, we decided to focus on the period from 1997 to 2017.

Table 1 shows the number of works per year, number of total publications, and percentage of publications on Mental Models with respect to all publications (% P-MM). As shown in Table 1, if we take the average percentage (0.0116%), we can see that the barrier of 0.01% is exceeded in 2004, and this figure stabilizes as of 2009. The number of publications between 2010 and 2017 reveals a steady growth rate.

Table 2 General structure of citations

Numbers of citations	Numbers of papers	Papers (%)
2000 cites	1	0.025
1000 cites	2	0.049
500 cites	9	0.222
250 cites	34	0.838
100 cites	164	4.042
50 cites	283	6.976
< 50 cites	3564	87.848
Total	4057	

Table 2 was prepared by filtering the records by number of citations. Articles with "N" citations were divided by total articles calculating the respective percentage. Table 2 shows that there are 3564 articles (87.8%) that have received less than 50 citations. The remaining 493 articles are distributed as a wide-based pyramid in which more than half fall in the range of 50–999 citations. At the peak of this pyramid, there are just three articles with more than 1000 citations.

The 30 most cited journals are presented in Table 3. It can be seen that the most influential journal in Mental Models is the *Journal of Applied Psychology* with an h-index = 7, a total of 3464 citations, and 26 published articles, of which one has received more than 500 citations, four have received more than 250, five have received more than 100, and three have received more than 50 citations. The second most influential journal is *Behavioral and Brain Sciences* magazine with an h-index = 5; it has a total of 2566 citations, two published articles with more than 500 citations and two others with more than 100 citations. In addition to the two already mentioned, the list of the top ten most influential publications is rounded out by the *Annual Review of Psychology* with 2366 citations, *Global Environmental Change-Human and Policy Dimensions* with 2347 citations, the *International*

Table 3 Most influential journal

R	Name	H-m	Tcmm	Tpmm	pmm (%)	>500	>250	>100	>50	Tp	Tc	IF	T50	H
1	Jnapppsy	7	3464	26	1.24	1	4	5	3	2097	252,397	4.643	6	235
2	Bebrsc	5	2566	5	0.07	2	0	2	0	6927	82,891	15.071	2	137
3	Glenvchgh	0	2437	10	0.65	1	0	1	0	1539	98,462	6.371	1	142
4	Annrevpsy	6	2366	11	2.07	1	2	4	2	531	158,574	22.774	4	208
5	Intjnsced	0	2197	87	4.08	0	0	5	5	2131	45,716	1.325	0	87
6	Hufac	0	1952	41	2.83	0	2	2	5	1447	37,181	2.371	2	85
7	Mcog	0	1949	75	3.09	0	0	3	8	2428	72,787	1.911	0	107
8	Jnexpsylmc	0	1865	46	1.87	0	0	5	5	2454	97,353	2.319	0	136
9	Acmgrev	10	1818	10	0.80	0	3	4	2	1252	189,015	8.855	3	222
10	Leins	1	1745	31	3.34	0	1	4	4	929	38,871	3.967	1	92
11	Acmgjn	4	1640	9	0.59	1	1	3	3	1520	233,325	6.7	2	260
12	Jnobe	2	1533	15	1.11	0	1	5	2	1347	86,315	4.229	1	145
13	Psyrev	0	1491	17	1.85	0	1	3	6	921	133,580	7.23	1	184
14	Jnmg	1	1467	9	0.79	1	1	1	2	1144	121,727	8.08	2	182
15	Jnrescte	4	1450	29	2.36	0	0	2	9	1228	51,663	3.21	1	105
16	Psybul	5	1434	5	0.49	1	0	1	1	1022	233,159	13.25	1	261
17	Cogsc	2	1372	30	2.71	0	0	5	5	1109	36,543	2.617	0	96
18	Psysc	2	1290	10	0.27	1	1	0	1	3761	267,959	6.128	2	222
19	Jnmginsy	8	1268	8	0.96	1	0	2	1	836	41,081	2.744	1	97
20	Stmgjn	0	1158	21	1.17	0	1	3	2	1789	226,735	5.482	1	227
21	Sydyrev	0	1150	31	7.47	0	1	2	1	415	8722	0.852	1	46
22	Jnedpsy	7	1057	11	0.76	0	2	2	1	1440	111,397	4.433	2	172
23	Smalgrre	0	992	19	2.96	1	0	2	1	642	14,739	1.163	1	58
24	Rian	0	967	35	1.16	0	0	1	4	3012	69,475	2.898	0	106
25	Neuron	1	936	1	0.01	1	0	0	0	8690	1,022,995	14.319	1	416
26	Oremet	2	918	12	1.94	0	1	2	3	619	41,312	4.918	1	92
27	Cog	0	912	29	1.06	0	0	1	7	2747	132,598	3.354	0	161
28	Jnexppsygen	6	803	12	0.98	0	1	1	3	1224	75,952	4.107	1	136
29	Obehudpr	1	730	16	1.41	0	0	3	2	1132	60,506	2.259	0	120
30	Dispros	0	719	26	4.63	0	0	1	2	561	14,172	1.789	0	55

R: ranking; Name: Journals Name; H-M: h-index of Mental Model; TCmm: Journals Total Citation of Mental Models; TPmm: Journal Total Publications of Mental Models; %Pmm: percentage of TPmm/TP; > 500, > 250, > 100, > 50: numbers of papers with more than 500, 250, 100, 50 citation about Mental Models; TP, TC: Journals total papers and citation; IF: Journal impact factor; H: Journal h-index; T50: number of papers including in table N°6. JNAPPPSY: Journal of applied psychology; BEBRSC: Behavioral and brain sciences; GLENVCHGH: Global environmental change-human and policy dimensions; ANNREVPSY: Annual review of psychology; INTJNSCED: International journal of science education; HUFAC: Human factors; MCOG: Memory & Cognition; JNEXPSYLMS: Journal of experimental psychology-learning memory and cognition; ACMGREV: Academy of management review; LEINS: Learning and instruction; ACMGJN: Academy of management journal; JNOBE: Journal of organizational behavior; PSYREV: Psychological review; JNMG: Journal of management; JNRESCTE: Journal of research in science teaching; PSYBUL: Psychological bulletin; COGSC: Cognitive science; PSYSC: Psychological science; JNMGINSY: Journal of management information system; STMGJN: Strategic management journal; SYBYREV: System dynamic review; JNEDPSY: Journal of educational psychology; SMALGRRE: Small group research; RIAN: Risk analysis; OREMET: Organizational research methods; COG: Cognition; JNEXPPSYGEN: Journal of experimental psychology-general; OBEHUDPR: Organizational behavior and human decision processes; DISPROS: Discourse processes

Journal of Science Education with 2197 citations, *Human Factors* with 1952 citations, *Memory & Cognition* with 1949 citations, *Journal of Experimental Psychology-Learning Memory and Cognition* with 1865, *Academy of Management Review* with 1818 citations, and *Learning and Instruction* with 1745 citations received. The most cited journals show a clear predominance in the areas of psychology, cognition, and education; only five journals are from the field of management.

Table 4 describes the impact factor of journals that published articles on Mental Models between 1997 and 2017. Recall that the impact factor is the result of the number of times that articles published in years *n*-1 and *n*-2 have been cited for articles published during year *n* (TC2 in Table 4)

Table 4 Publications impact factor

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
TP	76	98	116	112	112	104	120	146	112	145	166
TC	3562	5192	5433	6819	6391	5680	5099	6410	5818	9723	7777
TC2	209	193	233	263	225	233	338	340	370	408	453
TP2	164	167	174	214	228	224	216	224	266	258	257
IF	1.27	1.16	1.34	1.23	0.99	1.04	1.56	1.52	1.39	1.58	1.76
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	–
TP	162	182	238	243	262	299	288	340	375	361	–
TC	6248	4237	6876	5877	4024	4380	3280	2185	1153	624	–
TC2	666	719	764	835	1049	1112	1129	1413	1321	1216	–
TP2	311	328	344	420	481	505	561	587	628	715	–
IF	2.14	2.19	2.22	1.99	2.18	2.20	2.01	2.41	2.10	1.70	–

TP: total number of paper published in year *n*;; TC, total number of citations received from papers published in year *n*; TC2, total citations received in year *n*-1 and *n*-2 from year *n*; TP2, total number of papers published in year *n*-1 and *n*-2; FI, impact factor of year *n*

divided by number of articles published in years *n*-1 and *n*-2 (TP2 in Table). Thus, the impact factor is nothing more than the proportion of citations that actually occurred with respect to the maximum citations that could occur—assuming the maximum as one citation per publication. In Table 4, only in 2001 was the proportion of citations less than one. The maximum impact factor occurred in 2015 when it reached 2.41; that is to say that in that year the articles published in the previous 2 years were cited 2.41 times per publication. The average impact factor was 1.71 in 2007, which represents a turning point for these values. From that year on, the impact factor has an above-average value every year, i.e., the new publications continue or are simply based on publications of the previous 2 years. The dip seen in 2017 (1.70) could be a trend or just a fluctuation.

Table 5 lists the most cited articles, with “Resilience: the emergence of a perspective for social-ecological systems analyses” (Folke 2006) occupying first place with 2085 citations received overall and 160 citations per year. This article was published in the *Global Environmental Change-Human and Policy Dimensions* magazine, which is in the third place of the most influential journals on Mental Models. The second place in Table 5 is occupied by the article “Individual differences in reasoning: Implications for the rationality debate?” (Stanoich and West 2000) with 1414 citations received and 74 citations per year; it was published in the journal *Behavioral and Brain Sciences*, which is the second most influential journal. In addition to those mentioned, four of the 10 most cited articles are related to groups and work teams (the fourth, eighth, ninth, and tenth), one to the field of neuroscience (fifth), and two are related to memory (third and sixth). It is important to consider that the volume of citations is affected not only by the content of the publication but also by the thematic area that is referred to, e.g., biochemistry is cited more than acoustics (Narin et al. 1994). Table 5 also shows that there are specific issues that receive considerable attention, e.g., among the 50 most cited publications, 17 are specifically related to teamwork. Another noteworthy detail from this table is that practically all of the most cited articles were published after the year 2000.

Table 6 brings together the most influential authors in Mental Models. The most cited and published author is P.N. Johnson-Laird, with 40 published articles and 2039 citations. In second place is E. Salas, with 30 publications and 3380 citations. It is important to consider that E. Salas has more overall publications in the last 10 years (405) than Johnson-Laird (50), so it is possible to infer that Johnson-Laird has a higher level of specialization in Mental Models than Salas. The remaining 15 authors have an average of 14 publications with a fairly homogeneous distribution; the average citation rate of 485, on the other hand, shows a greater dispersion with eight authors falling above the average.

In the network map (Fig. 2), we can see that the largest nodes are those associated with psychology and education, as affirmed in Table 1. The nodes with the greatest number of links between them are “cognition,” “memory-cognition,” “memory,” “interpretation,” and “Johnson-Laird”; they form an association space that can account for a certain link between publications. An interesting element is that the “cognition” node can be seen as a connector between two areas of study; one relates to behavior, organizations, and ergonomics, and the other to cognitive processes such as memory and reasoning.

The density map (Fig. 3) shows the most cited topics, and it suggests that there is a heterogeneous area that links “teamwork” with “human factor,” “ergonomics” and “measurement”; the term “benefit” also appears marginally. This is related to Table 5, indicating a possible area of the current and future development in the team work research field.

Table 5 50 most cited papers

R	*J*	Tc	Title	Author/s	Year	C/a
1	Glenvchgh	2085	Resilience: the emergence of a perspective for social-ecological systems analyses	Folke, C	2006	160.4
2	Bebrsc	1414	Individual differences in reasoning: implications for the rationality debate?	Stanovich, Ke; West, Rf	2000	74.42
3	Psybul	1076	Situation models in language comprehension and memory	Zwaan, RA; Radvansky, GA	1998	51.24
4	Jnapppsy	957	The influence of shared mental models on team process and performance	Mathieu, Je; Heffner, Ts; Goodwin, Gf; Salas, E; Cannon-Bowers, Ja	2000	50.37
5	Neuron	936	Functional–anatomic fractionation of the brain's default network	Andrews-Hanna, J R.; Reidler, J S.; Sepulcre, J; Poulin, R; Buckner, R L.	2010	104
6	Bebrsc	847	What memory is for	Glenberg, Am	1997	38.5
7	Jnmginsy	797	A design science research methodology for information systems research	Peffers, K; Tuunanen, T; Rothenberger, M A.; Chatterjee, S	2007	66.42
8	Annrevpsy	767	Teams in organizations: from input-process-output models to IMOI models	Ilgen, Dr; Hollenbeck, Jr; Johnson, M; Jundt, D	2005	54.79
9	Jnmg	750	Team effectiveness 1997-2007: a review of recent advancements and a glimpse into the future	Mathieu, J; Maynard, M. T; Rapp, T; Gilson, L	2008	68.18
10	Psysc	737	Enhancing the effectiveness of work groups and teams	Kozlowski, S W. J.; Ilgen, D R.	2006	56.69
11	Smalgrre	542	Is there a big five in teamwork?	Salas, E; Sims, De; Burke, Cs	2005	38.71
12	Acmgjn	540	Building better causal theories: a fuzzy set approach to typologies in organization research	Fiss, P C.	2011	67.5
13	Acmgrev	470	Multilevel theorizing about creativity in organizations: a sensemaking perspective	Drazin, R; Glynn, Ma; Kazanjian, Rk	1999	23.5
14	Revedre	457	Policy implementation and cognition: reframing and refocusing implementation research	Spillane, Jp; Reiser, Bj; Reimer, T	2002	26.88
15	Acmgjn	429	Empowering leadership in management teams: effects on knowledge sharing, efficacy, and performance	Srivastava, A; Bartol, K M.; Locke, E A.	2006	33
16	Jnmkt	428	From embedded knowledge to embodied knowledge: new product development as knowledge management	Madhavan, R; Grover, R	1998	20.38
17	Psyrev	401	Conditionals: a theory of meaning, pragmatics, and inference	Johnson-Laird, P N.; Byrne, R M. J.	2002	23.59
18	Advphe	389	Where's the evidence that active learning works?	Michael, J	2006	29.92
19	Jnapppsy	379	Measuring transactive memory systems in the field: scale development and validation	Lewis, K	2003	23.69
20	Hufac	374	On teams, teamwork, and team performance: discoveries and developments	Salas, E; Cooke, N J.; Rosen, M A.	2008	34
21	Annrevpsy	368	Discourse comprehension	Graesser, Ac; Millis, Kk; Zwaan, Ra	1997	16.73
22	Jnobe	366	Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries	Mohammed, S; Dumville, Bc	2001	20.33
23	Jnexppsygen	347	Individual differences in rational thought	Stanovich, Ke; West, Rf	1998	16.52
24	Acmgrev	340	Relational archetypes, organizational learning, and value creation: extending the human resource architecture	Kang, S-C; Morris, S S.; Snell, S A.	2007	28.33
25	Stmgjn	338	Top management team diversity, group process, and strategic consensus	Knight, D; Pearce, Cl; Smith, Kg; Olian, Jd; Sims, Hp; Smith, Ka; Flood, P	1999	16.9
26	Psylemota	333	The immersed experiencer: toward an embodied theory of language comprehension	Zwaan, Ra	2004	22.2
27	Annrevpsy	331	Negotiation	Bazerman, Mh; Curhan, Jr; Moore, Da; Valley, Kl	2000	17.42
28	Leins	331	Construction and interference in learning from multiple representation	Schnotz, W; Bannert, M	2003	20.69

Table 5 (continued)

R	*J*	Tc	Title	Author/s	Year	C/a
29	Psysc	331	The representations underlying infants' choice of more: object files versus analog magnitudes	Feigenson, L; Carey, S; Hauser, M	2002	19.47
30	Adtscqu	330	Unpacking the concept of virtuality: the effects of geographic dispersion, electronic dependence, dynamic structure, and national diversity on team innovation	Gibson, C B.; Gibbs, J L.	2006	25.38
31	Jnapppsy	319	Performance implications of leader briefings and team-interaction training for team adaptation to novel environments.	Marks, Ma; Zaccaro, Sj; Mathieu, Je	2000	16.79
32	Resced	317	Promoting self-regulation in science education: metacognition as part of a broader perspective on learning	Schraw, G; Crippen, Kj; Hartley, K	2006	24.38
33	Presence	312	The experience of presence: factor analytic insights	Schubert, T; Friedmann, F; Regenbrecht, H	2001	17.33
34	Oremet	304	A content analysis of the content analysis literature in organization studies—research themes, data sources, and methodological refinements	Duriau, V J.; Reger, R K.; Pfarrer, M D.	2007	25.33
35	Amjnpubhe	302	Learning from evidence in a complex world	Sterman, Jd	2006	23.23
36	Jnedpsy	298	Does training on self-regulated learning facilitate students' learning with hypermedia?	Azevedo, R; Cromley, Jg	2004	19.87
37	Childdev	296	All other things being equal: acquisition and transfer of the control of variables strategy	Chen, Z; Klahr, D	1999	14.8
38	Sydyrev	291	All models are wrong: reflections on becoming a systems scientist.	Sterman, Jd	2002	17.12
39	Wilitrevcch	288	Communicating climate change: history, challenges, process and future directions	Moser, S C.	2010	32
40	Jnapppsy	286	Transactive memory in organizational groups: the effects of content, consensus, specialization, and accuracy on group performance	Austin, Jr	2003	17.88
41	Jnapppsy	280	The cognitive underpinnings of effective teamwork: a meta-analysis	Dechurch, L A.; Mesmer-Magnus, J R.	2010	31.11
42	Jnedpsy	277	When learning is just a click away: does simple user interaction foster deeper understanding of multimedia messages?	Mayer, Re; Chandler, P	2001	15.39
43	Hufac	276	Planning, shared mental models, and coordinated performance: an empirical link is established	Stout, Rj; Cannon-Bowers, Ja; Salas, E; Milanovich, Dm	1999	13.8
44	Acmgrev	266	Team implicit coordination processes: a team knowledge-based approach.	Rico, R; Sanchez-Manzanares, M; Gil, F; Gibson, C	2008	24.18
45	Psycorev	264	The heuristic-analytic theory of reasoning: extension and evaluation	Evans, J St B. T.	2006	20.31
46	Jnmg	260	Metaphor no more: a 15-year review of the team mental model construct	Mohammed, S; Ferzandi, L; Hamilton, K	2010	28.89
47	Annrevpsy	246	Self-regulated learning: beliefs, techniques, and illusions	Bjork, R A.; Dunlosky, J; Kornell, N	2013	41
48	Jnapppsy	245	The impact of cross-training on team effectiveness	Marks, Ma; Sabella, Mj; Burke, Cs; Zaccaro, Sj	2002	14.41
49	Eclm	243	Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach	Ozesmi, U; Ozesmi, Sl	2004	16.2
50	Jnrescte	241	Promoting understanding of chemical representations: students' use of a visualization tool in the classroom	Wu, Hk; Krajcik, Js; Soloway, E	2001	13.39

R: ranking; J: Journal—Journal abbreviations are available in table N°3; TC: total citations; C/A: annual citation

Conclusions

This descriptive work has sought to outline the general picture of Mental Models publications and discern the future developments in the field. We searched *Web of Science* for the terms "Mental Model" and "Mental Models," filtering by articles, reviews, and proceeding paper. The results were processed, obtaining 4805 records. Considering the

Table 6 Most influential authors

Nombre	País	TP-MM	TC-MM	H-M	H	TP10	TC10	T50	TP	TC
Johnson-Laird, P N.	Reino Unido	40	2039	0	31	59	1054	1	101	3324
Salas, E	Estados Unidos	30	3380	1	69	405	7900	4	590	19,090
Byrne, R M. J.	Irlanda	21	973	1	37	301	3759	1	353	3992
Barrouillet, P	Suiza	18	534	3	94	94	3431	0	94	3434
Knauff, M	Alemania	18	464	0	18	35	395	0	59	1267
Bostrom, A	Suecia	15	427	5	49	204	4549	0	329	8789
Bucciarelli, M	Italia	15	222	0	16	40	284	0	59	762
Copeland, D E.	Estados Unidos	15	487	4	38	115	1611	0	234	4884
De Beni, R	España	15	613	1	25	63	1323	0	92	2560
Brunye, T T.	Estados Unidos	14	267	6	21	92	1231	0	93	1276
de Bruin, W B	Alemania	14	605	0	36	172	2924	0	212	4633
Schnotz, W	Alemania	13	534	0	18	44	698	1	61	1663
Oaksford, M	Inglaterra	12	654	2	22	31	602	0	62	1651
Vosniadou, S	Grecia	12	733	1	17	18	410	0	30	1224
Markovits, H	Canadá	11	171	0	19	44	308	0	66	1209
Chater, N	Inglaterra	10	640	2	45	106	3270	0	174	6748
Doohan, D	Irlanda	10	108	0	14	37	368	0	57	804

TP-M, total Mental Models publications; TC-M, total Mental Models citation; H-M, Mental Models h-index; H, h-index; TP10 y TC10: total publications and citation in the last 10 years; T50: numbers of publications in table N°5 (50 most cited papers); TP y TC: total publications and cites

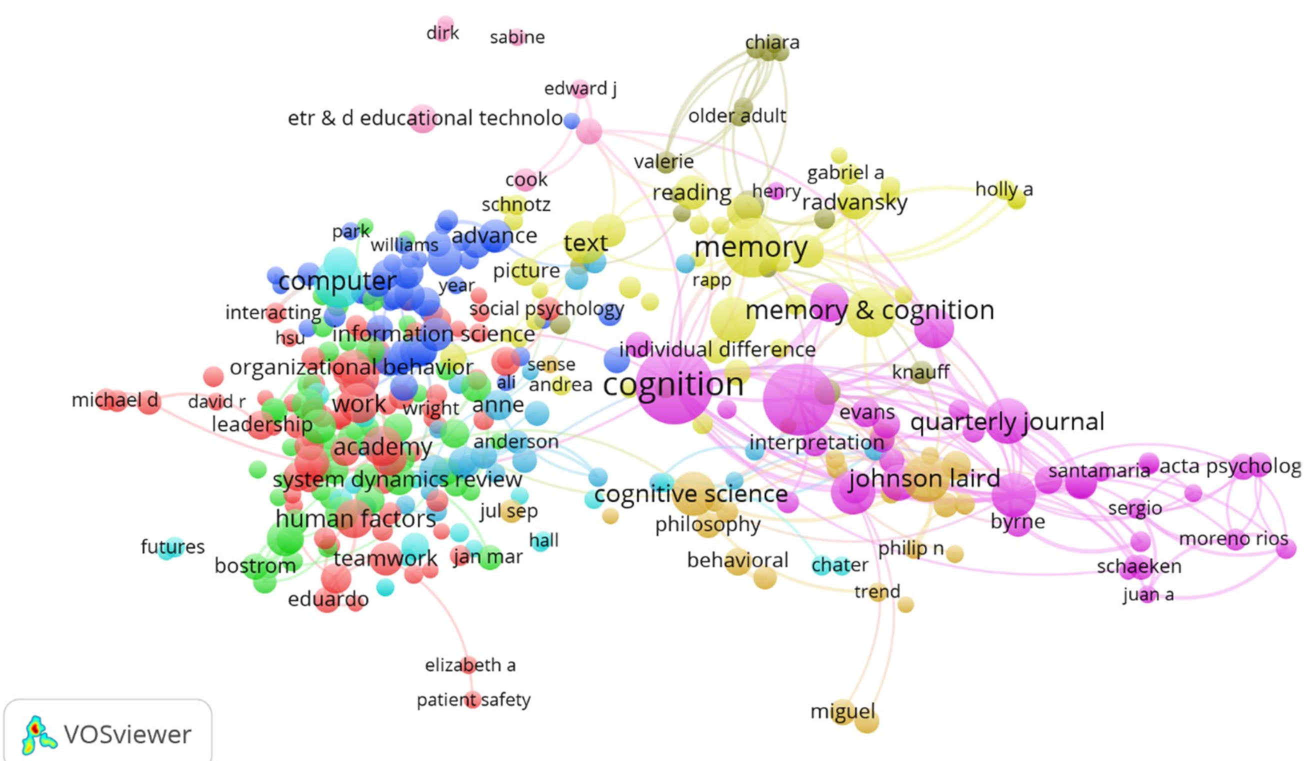

Fig. 2 Network mapping

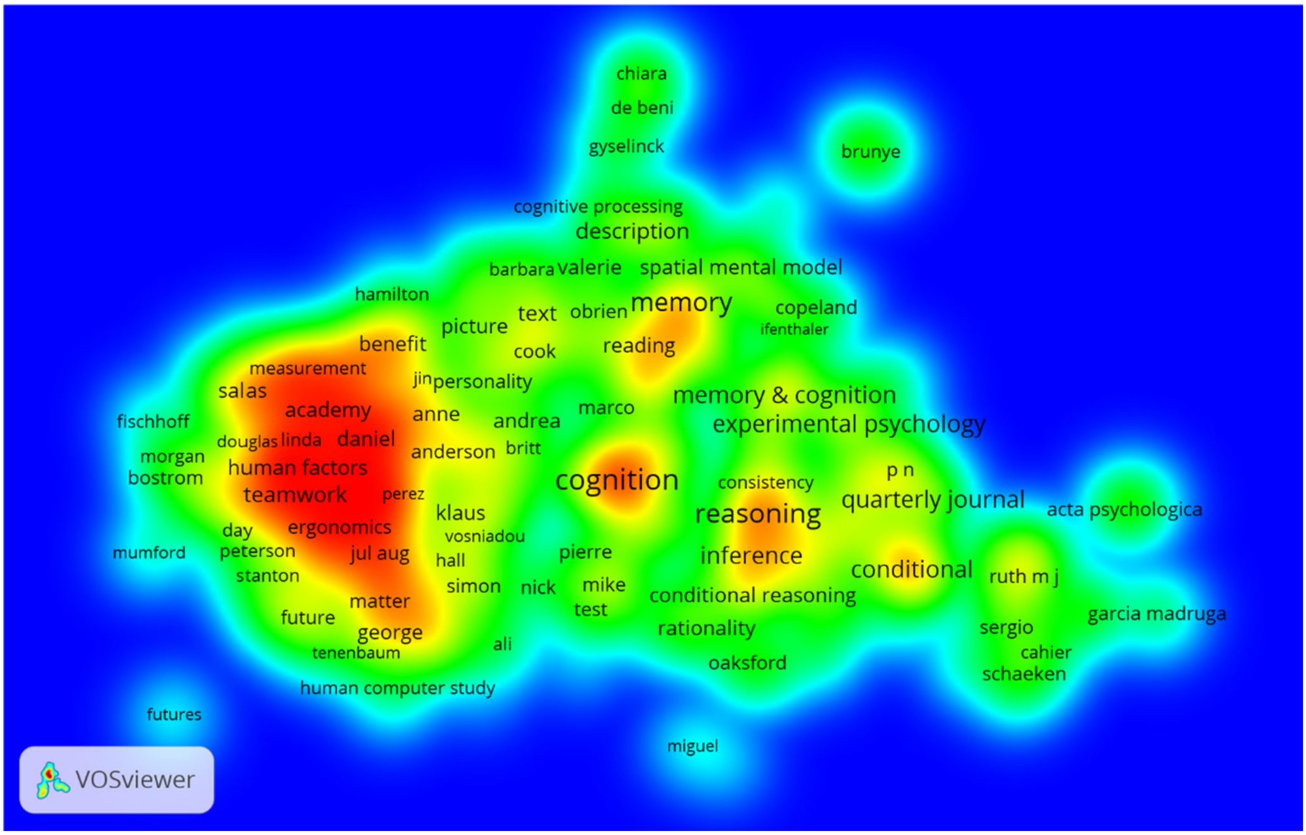

Fig. 3 Density mapping

evolution of publications from 1976 to October 2018, we decided to concentrate on data from 1997 to 2017.

A bibliometric analysis of the data was carried out, which enabled us to measure the production and links between various publications, journals, and authors. Tables were made with the most cited publications, journals with the most publications, and the most published authors (Bar-Ilan 2008). The value of the bibliometric indicators such as the h-index, impact factor, threshold of citations, total of publications, total of citations, and the average of citations was obtained. Finally, bibliometric mapping was performed (Merigo et al. 2016) using VOSviewer software (Van Eck and Waltman 2009).

The results obtained allow us to propose the existence of a progressive and non-explosive development of publications on Mental Models. In our opinion, the real takeoff of publications began at the end of the 1990s and significant growth continued throughout the 1900s; since 2010, growth has slowed but continues to be steady.

The data show that publications are made predominantly in the area of individual and organizational psychology, as well as in education. This predominance is reflected in the ranking of magazines, publications, and authors and is consistent with the concept's origin (Craik 1943).

The evolution of impact factors reveals that as of 2007, the publications begin to constitute a corpus; that is to say, the investigations are built on previous ones or are based on them. This corpus covers topics such as memory, cognition, and interpretation; the author Johnson-Laird appears as a link between these fields, as we see in Fig. 2.

In the late 2000s, publications associated with team work, e.g., issues such as performance, ergonomics, and even Team Mental Models, in our opinion have the potential to form a new corpus, as we see in Fig. 3.

Science can be viewed as an autopoietic system, i.e., a system that is self-producing by publications (Luhmann 1997, p. 111; Luhmann 2007, p. 607). In that sense, both Figs. 2 and 3 show us poles of the current and future growth in the form of corpora, like an engine that keeps the system in motion.

The limitations of this work are related to its methodology, e.g., calculating the h-index, considering a unique authorship for each publication. Another limitation is that no sources other than Web of Science, such as Scopus or Google Scholar, are included; maybe in another analysis we could sacrifice precision for scope and include more sources.

Future research aims to broaden the search with new engines such as those already mentioned and other sources such as associations and conferences. Bibliometric analysis could also be done in specific fields that study Mental Models such as psychology, education, or management in order to determine the differences between their respective descriptive studies and identify development gaps.

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Compliance with ethical standards

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