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A Bibliometric Analysis of Project-Based Learning Research in and Outside Mainland China*

SHUANG LIN[1], ZHENGTANG TAN[2] and WENPING GUO[3]
[1] School of Art & Design, Taizhou University, Taizhou 318000, China.
[2] College of Engineering & Design, Hunan Normal University, Changsha 410000, China.
[3] School of Electronics and Information Engineering, Taizhou University, Taizhou 318000, China.
Corresponding author: Zhengtang Tan (E-mail: tanzhengtang@hunnu.edu.cn)

Project-based learning (PBL) is a student-centered form of instruction which focuses on students' investigation, participation, collaboration and solving problems in real world practices. It has been identified to be a multitude of strategies critical for success in the 21st century. This paper examines the evolution of PBL research in and outside mainland China by using visualization analysis with CiteSpace. First, we retrieve 2624 English language articles from Web of Science (WoS), and 521 Chinese language articles from CNKI respectively during the period from 2000 to 2021. By analyzing publication trends, core countries/regions, core institutions, core journals, this paper identifies the development trajectories and topical trends of PBL research in mainland Chinese and international journals. Second, according to the timeline of visualization of the major clusters in international journals, as well as time zone view of keywords and citation with strongest bursts in mainland Chinese journals, this paper expounds upon the intellectual base and evolution process of each stage in each field. The researchers focus on different research issues with different perspectives in and outside mainland China, while few cross-border research collaborations are observed among them. Finally, this paper puts forward some suggestions for researchers and educators, including in-depth study of PBL hot topics, introduction of international projects, encouragement of academic exchanges, etc., in order to better establish international contacts, create opportunities for cross-border cooperation and promote the development of PBL.

Keywords: project-based learning (PBL); skills; education; bibliometric analysis

1. Introduction

Project-based learning (PBL) is derived from the teaching philosophy of ''learning by doing'', ''inquiry-based learning'' and the theory of ''experiential learning'' [1, 2]. Because of its emphasis on practicality and participation, problem-solving as the center, and integration of various learning methods, it has realized the educational reform of ''learner-centered'' and ''ability-centered'' [3, 4]. It has been widely used in K-12 education, vocational or adult education and higher education all over the world. It has played an important role in cultivating students' practical ability, teamwork ability, communication ability, practical management ability and other 21st century skills, and has produced a large number of research achievements in theoretical construction and implementation research [5]. Several researchers made reviews of research on PBL. Thomas and MDRC have an agreement on the definition of PBL and the effectiveness of cultivating students' ability in K-12 settings [6]. MDRC assessed implementation and effectiveness of PBL, and recommended priorities for advancing the PBL research literature further [7]. They also expounded the challenges associated with PBL implementation in different periods, and put forward the future directions of PBL research. Helle discussed the psychological motivation of supporting project-based learning, made an empirical analysis on the implementation effect of PBL in individual courses in post-secondary education based on literature of PBL [8]. International journals such as *International Journal of Engineering Education*, *Journal of Engineering Education*, and *Educational Psychologist* have made systematic and diversified research on PBL.

PBL was first introduced into the field of vocational education in mainland China in the late 1990s, and gradually penetrated into the fields of basic education and higher education in the 21st century. With the ''National Medium-and Long-Term Education Reform and Development Plan (2010–2020)'', the ''Excellent Engineer Education and Training Plan'' and ''Emerging Engineering Education'' Policies launched in 2010 and 2017 respectively, project-based learning, as a ''learner-centered'' teaching method, has become one of the curriculum teaching forms, aiming at optimizing students' knowledge structure, enriching social practice and improving students' skills of communication, negotiation, and collaboration [9]. Thus, more and more mainland Chinese teachers and scholars are doing theoretical and practical research on PBL [10]. In the core journals of mainland China education, such as *Higher Education*

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Research, Higher Engineering Education Research and *Chinese University Education*, there are also systematic reviews on the teaching characteristics, students' ability development, teaching technical support and evaluation methods of PBL, which provide some in-depth insights for the PBL.

However, these reviews describe the articles published in and outside mainland China relatively separately, although there is a close relationship between in and outside research. Meanwhile, as far as the research environment and development history are concerned, they will inevitably experience different development trends. Therefore, this paper makes a bibliometric analysis and visual display on the research trends of PBL in and outside mainland China in recent 20 years, so as to show their respective research hotspots and future trends. This will help to build a bridge or share knowledge base for the two groups of researchers to conduct fruitful exchanges with each other. In order to better grasp the overall development trends of PBL research in and outside mainland China, clarify their core issues, and compare the intertwining and interaction between them, this study uses bibliometric tools to describe the development track and frontier trends of PBL research in and outside mainland China and provides corresponding visual landscape maps. In addition, this study also identifies core countries/regions, core institutions, core journals, core research fields and knowledge structures, and compares the relationships and differences between them, so as to provide more accurate suggestions and references for the research and development of PBL.

In order to achieve these goals, this paper makes a bibliometric analysis of the articles that are published in international journals and in mainland Chinese journals from 2001 to 2021. The study will address the following research questions:

1. What is the current status of PBL publication outputs in and outside mainland China?
2. What are the main contributing countries/regions and the core institutions, authors and journals?
3. What is the intellectual base of PBL research in and outside mainland China?
4. How has PBL research evolved from 2000 to 2021 in and outside mainland China?

2. Data and Methods

2.1 Data Collection

To ensure the equivalence of articles comparison in and outside mainland China, this study uses two databases that are representativeness and completeness: Web of Science (WoS) in international and CNKI in mainland China.

(1) In terms of international articles, the data sources mainly came from Citation Indexes of SCIE, SSCI, A&HCI, ESCI in the core Collection of WoS, to guarantee the diversity and intersection of disciplines involved in PBL research. The data was retrieved on June 16, 2021. Fig. 1 shows the retrieval strategies in detail. The final data set is set # 9, containing 2692 English bibliographic records of articles or comments. Eliminate articles that do not conform to the theme of PBL. Eventually, 2624 records were finally confirmed.

(2) Concerning mainland China's articles, the database CNKI is selected as it is the largest full-text database of Chinese mainland journals in the world, covering almost all research disciplines. Taking into consideration the potential impact and quality of related research in this field, the review of Chinese publications was limited to journals listed in the China Social Sciences Citation Index (CSSCI). We obtain 686 records by searching of the title with TS = "object" and ("teaching" or "learning"). Exclude book reviews and irrelevant articles by manual method. Finally, 521 records were confirmed.

2.2 Methods and Tools

In this paper, by adopting the literature research method and bibliometrics to analyze the dynamic development of PBL research in and outside mainland China. We use CiteSpace and the embedded bibliometric analysis tool of CNKI. CiteSpace focuses on the evolution of a knowledge field on the citation network map, which identifies the research frontier hotspots represented by citation node literature and co-citation clustering. Unfortunately, some functions are not suitable for CNKI. Therefore, the embedded bibliometric analysis tool of CNKI can make up for the shortage of literature analysis in mainland China PBL research. Fig. 2 shows the framework of this study, including tools, methods and processes.

3. Results and Discussion

3.1 Publication Trends

Fig. 3 shows the publication trends of PBL in WoS and CNKI databases during 2000–2021. Overall, the number of publications in international journals was much bigger than that in mainland Chinese journals each year. Although the number of publications in international journals showed a slow growth trend during 2000–2014, it increased obviously in 2003 and 2010, which was directly related to the education policies. For example, an action-oriented project pedagogy developed by the

Set	Results	Save History / Create Alert | Open Saved History
# 9	2,692	#8 AND #4 *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 8	1,317,435	#7 OR #6 OR #5 *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 7	746,656	**TOPIC:** (learning) *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 6	215,312	**TOPIC:** (teaching) *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 5	617,333	**TOPIC:** (education) *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 4	4,856	#3 OR #2 OR #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 3	45	**TOPIC:** ("project centered") *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 2	282	**TOPIC:** ("project oriented ") *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*
# 1	4,566	**TOPIC:** ("project based") *AND* **DOCUMENT TYPES:** (Article OR Review) *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=2000-2021*

Fig. 1. Topic search queries used for data collection in WoS.

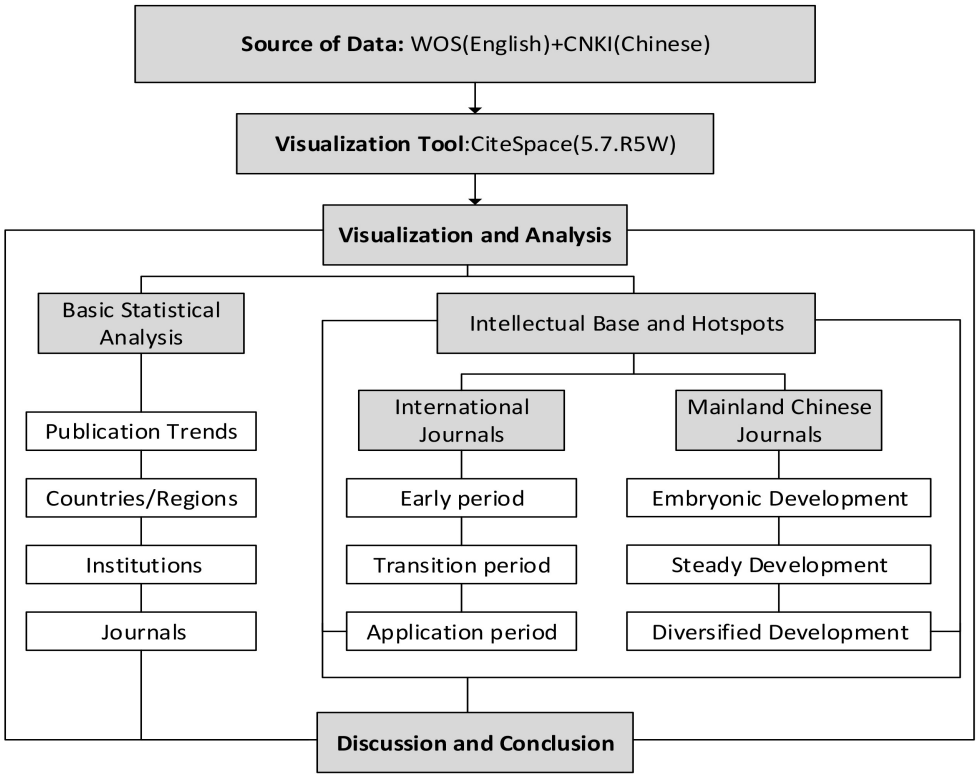

Fig. 2. Research framework.

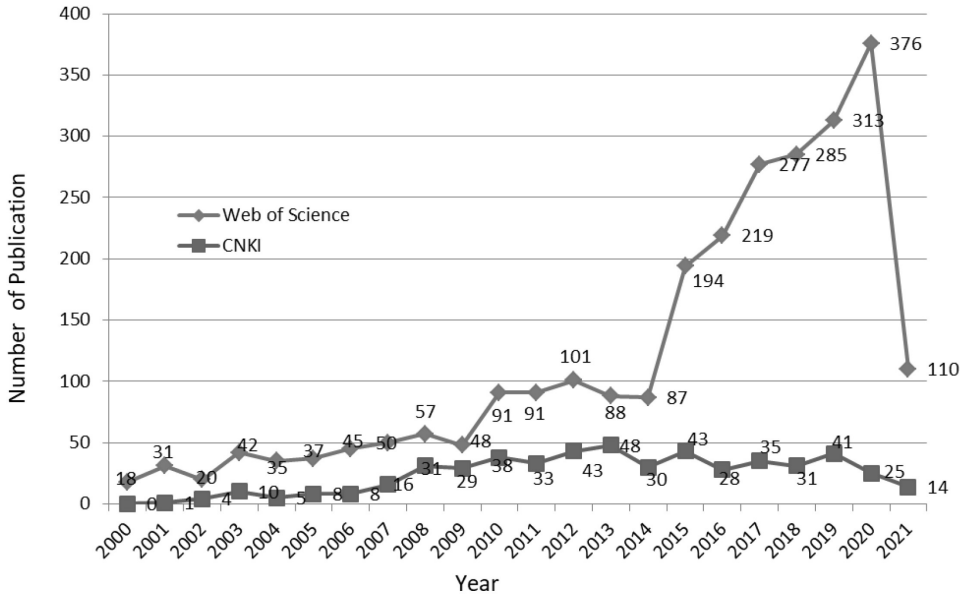

Fig. 3. Publication trends of PBL research in WoS and CNKI.

German Federal Vocational Education Institute promoted the research of PBL in 2003 [11]. With the promotion of education reform and the strong support of funds in various countries (for example, OBAMA (2015) put out ''Preparing Americans with 21st Century Skills: STEM Education in the 2015 Budget'' [12], investing $2.9 billion on STEM education), the number of publications in international journals has shown a rapid growth trend since 2015. In contrast, PBL was first introduced into mainland China in 1999. The average annual number of publications in Chinese journals was only 6 during 2000–2007. With the popularization, application and implementation effect of PBL in all stages and disciplines of education since 2008, more and more scholars have engaged in PBL research, and the number of publications in Chinese journals has gradually increased, forming a research upsurge.

3.2 Top Productive Countries/Regions, Institutions and Journals in and Outside Mainland China

Table 1 shows the top 10 productive countries sorted by the quantities of their published articles in descending order in the field of PBL research. The USA ranked first with 842 publications, or about 32% of the total. Follow by Spain (262), Mainland China (140), England (140), and Australia (118). The articles of above top 5 productive countries account for more than half of the total.

Among 565 institutions in the PBL research in international journals, the top 10 institutions are listed in Table 2, all of which are universities. University of Michigan with 32 articles is the most prolific institution represented on the PBL research, followed by Israel Institute of Technology (21) and Purdue University in the USA (20). Universidad Politécnica de Madrid, The University of Hong Kong, Stanford University, Arizona State University and Aalborg University each published more than 15 articles in international journals. This indicates that these institutions have influence in the field of PBL. In addition, half of the top 10 institutions are in the USA, which shows that institutions in the USA have made great contributions to PBL research. Unfortunately, the institutions of mainland China have not appeared in the top 10 institutions in international journals. As for the top 10 institutions in mainland China (Table 2), Beijing Normal University performed well and ranked in the first position with 39 articles published, followed by East China Normal University

Table 1. Top 10 productive countries of PBL-related articles in international journals

Ranking	Counts	Centrality	Country	Ranking	Counts	Centrality	Country
1	842	0.53	USA	6	105	0.00	Taiwan China
2	262	0.19	Spain	7	90	0.06	Canada
3	140	0.11	Mainland China	8	87	0.00	Turkey
4	140	0.18	England	9	86	0.06	Germany
5	118	0.13	Australia	10	64	0.00	Israel

Table 2. Top 10 productive institutions of PBL-related articles in and outside mainland China

Ranking	Counts	Institution	Country	Ranking	Counts	Institutions in mainland China
1	32	Univ. Michigan	USA	1	39	Beijing Normal University (北京师范大学)
2	21	Technion Israel Inst. Technol.	Israel	2	19	East China Normal University (华东师范大学)
3	20	Purdue Univ.	USA	3	14	South China Normal University (华南师范大学)
4	19	Univ. Politecn Madrid	Spain	4	11	Shaanxi Normal University (陕西师范大学)
5	17	Univ. Hong Kong	Hong Kong, China	5	10	Peking University (北京大学)
6	17	Stanford Univ.	USA	6	10	Nanjing Normal University (南京师范大学)
7	16	Arizona State Univ.	USA	7	9	National Center for Educational Technology (中央电化教育馆)
8	16	Aalborg Univ.	Denmark	8	9	Northeast Normal University (东北师范大学)
9	15	Natl. Taiwan Normal Univ.	Taiwan, China	9	9	Central China Normal University (华中师范大学)
10	14	Michigan State Univ.	USA	10	8	Shanghai Normal University (上海师范大学)

(19), South China Normal University (14), Shaanxi Normal University (11), Peking University (10), Nanjing Normal University (10), and National Center for Educational Technology (9), etc. Regarding the nature of these institutions, nine institutions were universities, while one was an academic institution. Among these institutions, only Peking University is a comprehensive university, and others are all educational institutions.

Table 3 shows the top 10 journals that published PBL-related research in and outside mainland China. International journal of engineering education, which is a journal designing learning for innovations and improving students' employability skills of engineering, published the highest number of PBL papers. Most of the top 10 journals had research studies focused on education, except the journal of Sustainability in international and the journal of Zhuang Shi in mainland China. The journal of Zhuang Shi is the one of top journals in the field of art & design in mainland China, which reflects the multidisciplinary features of the PBL domain.

Further analysis reveals that the number of PBL-related articles from USA is highest in international journals. It also has higher influence with centrality (0.53). This is mainly because USA is a powerful country in education. The idea of education reform was formed earlier, and PBL was widely popularized by the state. The stem education development plan and goal put forward by the federal government of the United States and the development strategy of strengthening the country by education have contributed to the current situation of the largest amount of study and the highest influence in the United States, showing strong scientific research strength. In contrast, the number of PBL-related articles from mainland China published in international journals ranks third, which is directly related to the strong policies and reform measures adopted by the mainland Chinese government for education development in the past 10 years. However, it still unable to enter the top 10 institutions of PBL-related articles in international journals. The nature of institutions in mainland China has strong homogeneity and comprehensive institutions outside mainland China (Table 2), which indicates that the interdisciplinary research field of PBL research needs to be strengthened, and the research strength needs to be strengthened. Mainland China's influence in the field of PBL research is low with centrality (0.11), which indicates that mainland China's national influence on PBL literature in the world needs to be further improved.

3.3 Intellectual Base of PBL Research in International Journals

The document co-citation network can be a crucial means to detect the structure and evolution path of a specific domain [13]. The co-citation network is generated by running CiteSpace. Fig. 4 shows the

Table 3. Top 10 journals of PBL-related articles in and outside mainland China

Ranking	Counts	Journal		Ranking	Counts	Journals in mainland China
1	247	*International Journal of Engineering Education*		1	42	*China Educational Technology* (*中国电化教育*)
2	90	*IEEE Transactions on Education*		2	35	*E-education Research* (*电化教育研究*)
3	44	*Computer Applications in Engineering Education*		3	31	*Modern Educational Technology* (*现代教育技术*)
4	44	*Sustainability*		4	29	*Journal of The Chinese Society of Education* (*中国教育学刊*)
5	42	*European Journal of Engineering Education*		5	27	*China University Teaching* (*中国大学教学*)
6	39	*Journal of Chemical Education*		6	27	*Research in Higher Education of Engineering* (*高等工程教育研究*)
7	32	*International Journal of Electrical Engineering Education*		7	21	*Distance Education in China* (*中国远程教育*)
8	30	*International Journal of Emerging Technologies in Learning*		8	19	*Zhuang Shi* (装饰)
9	28	*Computers Education*		9	17	*Journal of Distance Education* (*远程教育杂志*)
10	27	*International Journal of Technology and Design Education*		10	16	*Theory and Practice of Education* (*教育理论与实践*)

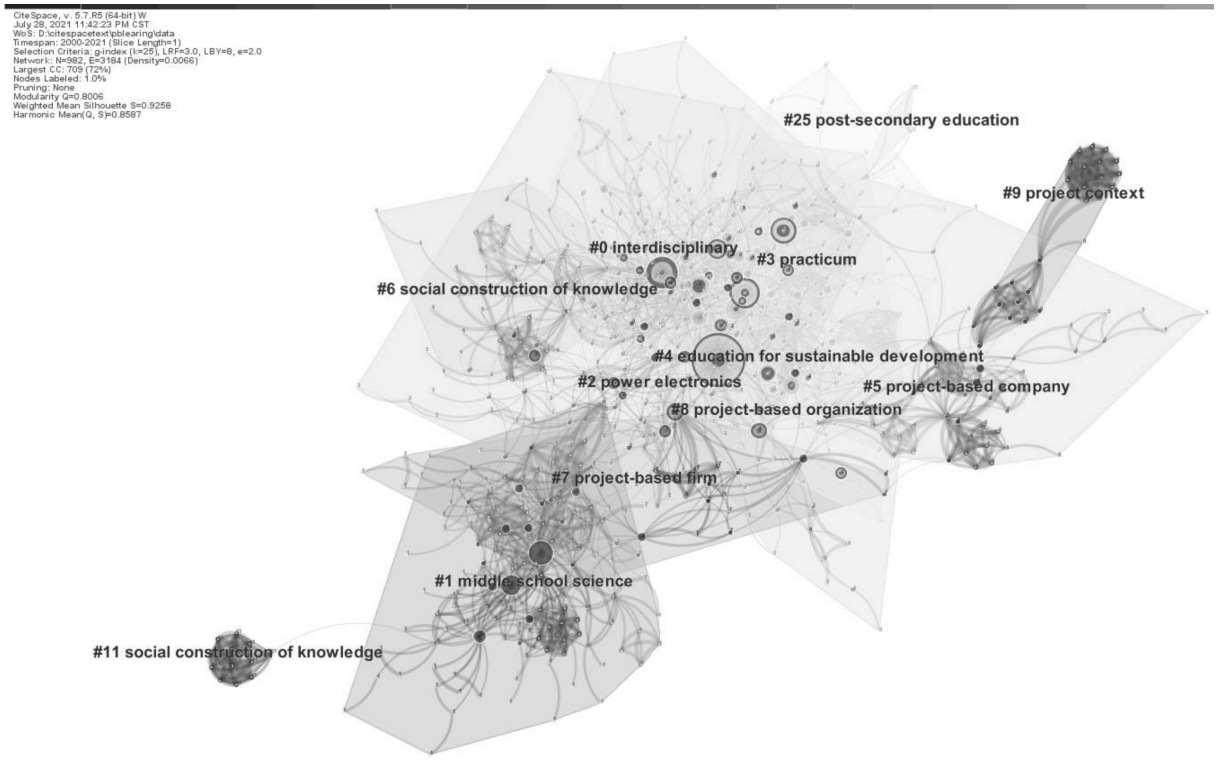

Fig. 4. Co-citation network in international journals between 2000 and 2021 (LRF = 3.0, LBY = 8, e = 2.0).

co-citation and citation burst of literatures regarding PBL between 2000 and 2021 in international journals. Citation burst represents the most active research field, which is marked with red circle, and can clearly track the focus of its discipline field [14]. The network has modularity of 0.8006, which is considered as very high, suggesting that the specialties in PBL are clearly defined in terms of co-

Table 4. Details of the major clusters of co-cited network

Cluster ID	Label (LLR)	Size	Silhouette	Mean (Year)
0	Interdisciplinary	138	0.859	2012
1	Middle school science	121	0.974	2000
2	Power electronics	99	0.860	2009
3	Practicum	65	0.906	2015
4	Education for sustainable development	63	0.960	2014
5	Project-based company	54	0.952	2005
6	Social construction of knowledge	51	0.977	2006

citation clusters. The average silhouette high score of 0.9258, indicating high cluster homogeneity. The areas of different colors indicate the time when co-citation links in those areas appeared for the first time. The purple areas were produced earlier than the blue areas. Green areas were generated after the blue areas and so on. Each cluster is labeled by keywords of citing articles to the cluster, and only major clusters are shown in Fig. 4. According to the existing analyses, PBL is a topic which pays less attention to the intellectual base and research fronts, but has a wide radiation range. The intellectual base is the collection of scholarly works cited by the corresponding research community, whereas research fronts are the works inspired by the ones of the intellectual base [15]. Hence, we will particularly focus on the seven largest clusters including size, silhouette and mean (year) for further focus and deep discussion (Table 4).

Timeline visualization provides a temporal overview of nodes, links, and clusters that graphs the publication years of cited papers with the derived clusters. We get Fig. 5 through running Citespace, which summarizes the intellectual base of PBL and hotspots evolution. Although we extract literature during 2000–2021, the timeline visualization provides the earlier literature which is cited in the paper published in the period. It helps us to analyze the intellectual base and development trend of PBL comprehensively. The most obvious trend in Fig. 5 is that all of clusters lasted for a few years, which indicates that hotspots of PBL research changes with the times. We divide it into three phases based on the timeline visualization. Early research focused on middle school science, project-based firm, project context, project-based company and social construction of knowledge. The second stage belongs to the transitional period, which includes the early research hotspots and the follow-up research frontiers. In recent ten years, we have realized the complexity of world challenges and the higher requirements of enterprises for students' abilities. All stakeholder groups made an agreement that students need success skill and a sense of responsibility to cope with the challenges of their own lives and the world in which they live as well as the key knowledge and understanding. Therefore, scholars in the field of PBL research in international paid more attention to the sustainable development of improving students' core literacy and ability. Accordingly, the clusters of interdisciplinary, power electronics, practicum and education for sustainable development as shown in Fig. 5 have become research hotspots.

3.3.1 Stage I: Early Period (–2003)

Fig. 5 shows that researchers focused on middle school science, social construction of knowledge, project-based company and project-based firm research on PBL in the early stage. We intercepted from Fig. 5 the time periods in Cluster 1 that made outstanding contributions to the development of middle school science for further analysis (Fig. 6). Table 5 lists major citing articles on middle school science. A study shows that middle school students were thoughtful in designing investigations and in planning procedures, but they failed to focus on the scientific merit of questions generated and to systematically collect and analyze data and draw conclusions [16]. Blumenfeld posed a framework for use by developers of instructional interventions to gauge their "fit" with existing school capabilities, policy and management structures, and organizational culture [17]. National Science Education Standards (1996) and Inquiry and the National Science Education Standards (2000) made a guide for learning and teaching of middle school science. All findings help curriculum developers and science educators in their attempts to design instruction to improve the inquiry process in middle school. Cluster 1 has declined since 2010, which does not mean that researchers lost their interest in the implementation of PBL in middle school. Rather, they shifted their focus to explore more stages and grades of PBL implementation.

As Fig. 5 shows researchers also studied the project context (cluster 9), the project-based company (cluster 5) and project-based firm (cluster 7), the latter two are only different in name and essentially the same. Fig. 7 shows the high-impact literature in details. Thomas defined five criteria for PBL: centrality, driving question, constructive

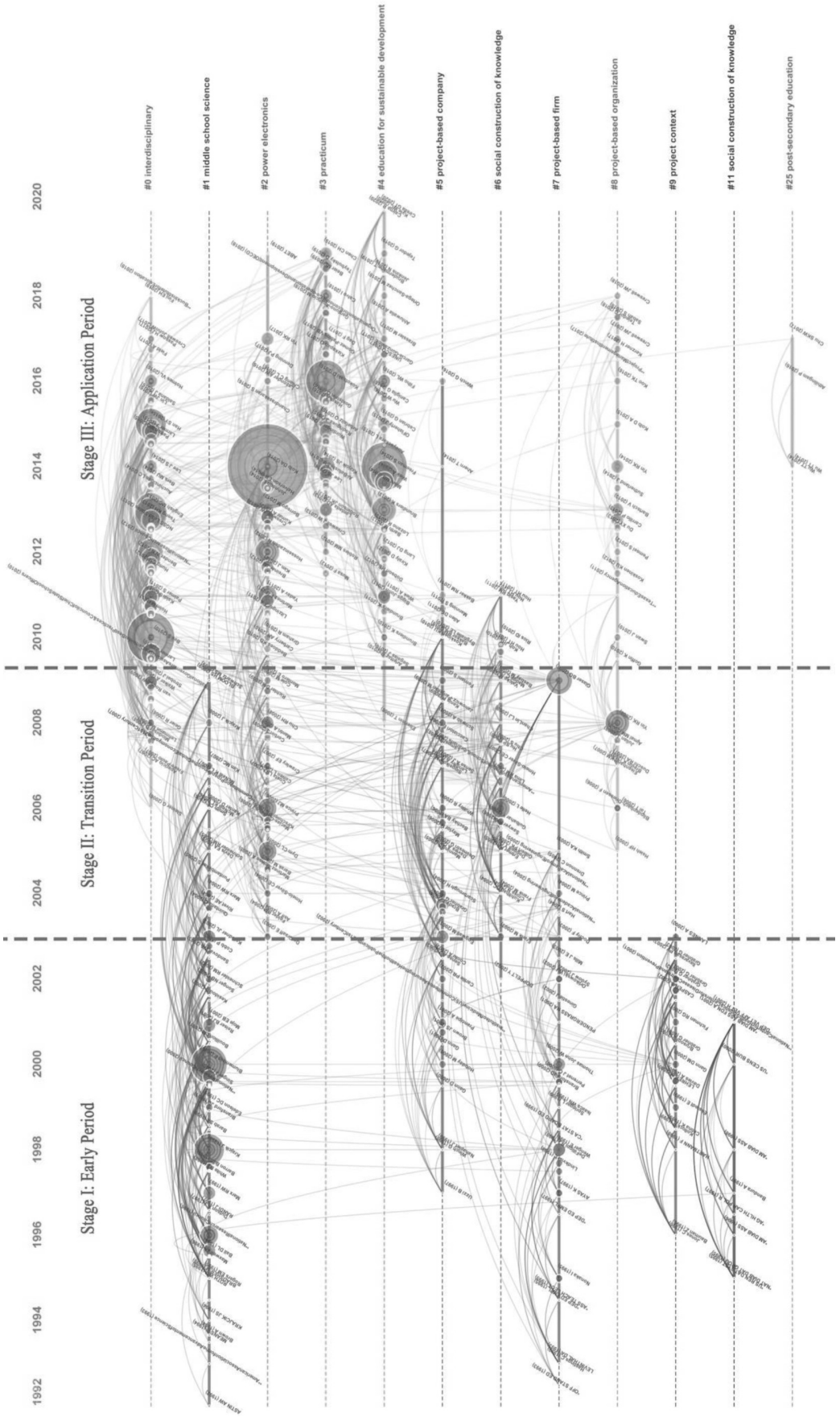

Fig. 5. A timeline visualization of the major clusters.

Table 5. Major citing articles to Cluster 1 on middle school science

Freq.	Burst	Author	Year	Journal	Title
22	12.13	Krajcik J.	1998	*Journal of the Learning Sciences*	Inquiry in Project-Based Science Classrooms: Initial Attempts by Middle School Students
20	10.23	Blumenfeld P.	2000	*Education Psychologist*	Creating Usable Innovations in Systemic Reform: Scaling Up Technology-Embedded Project-Based Science in Urban
9	4.87	Singer J.	2000	*Educational Psychologist*	Constructing extended inquiry projects: Curriculum materials for science education reform
8	4.73	Kolodner J.L.	2003	*Journal of the learning sciences*	Putting a student-centered Learning by Design™ curriculum into practice: Lessons learned
7	3.56	Moje E.B.	2001	*Journal of Research in Science Teaching*	"Maestro, what is 'quality'?": Language, literacy, and discourse in project-based science

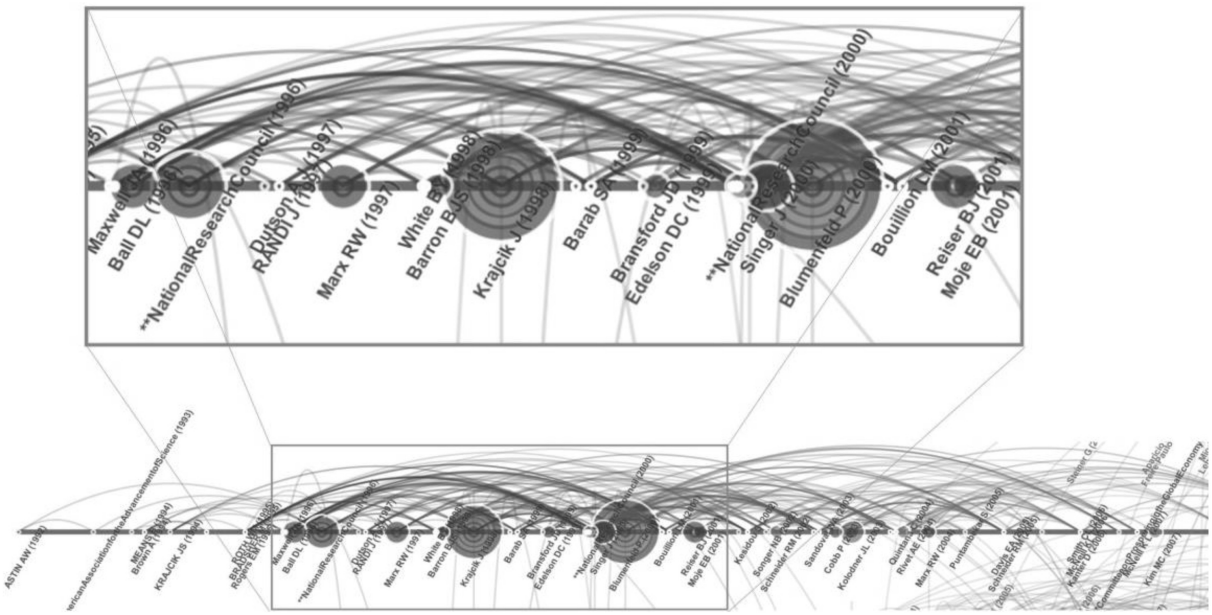

Fig. 6. High-impact members of Cluster 1.

investigations, autonomy, and realism. He emphasized that PBL projects are central, not peripheral to the curriculum [18]. The project does not exist in isolation, but is related to the prior, present and future vertically, as well as relationship with the project context horizontally [19]. By adopting such a contextual perspective, a conceptual framework around the notion of the project ecology was built for analyzing process of PBL [20]. All the results are helpful to explore the feasibility of combining the project with the curriculum.

From the Fig. 5 and the above analysis, it can be concluded that in the early stage, researchers focus on the characteristics of the project (such as reality) and the teachers, students and project context related to the project. Researchers also realize that PBL is closely related to the real world and social relations, and they also pay attention to social construction of knowledge, which has greatly developed in Stage II. Therefore, this paper will analyze it later in stage II. In addition, the research on PBL mainly focuses on K-12 education at this stage, especially for middle school science education, and rarely involves post-secondary education.

3.3.2 Stage II: Transition Period (2004–2009)

The research hotspots underwent subtle changes during this stage. First, the application of PBL, which prevailed in middle school science in stage I is still in progress, but it is obviously decreased. Meanwhile, researchers began to explore PBL in the research of engineering education, of which power electronics is one of the representatives. It indicates that implementation of PBL has started to go over to other disciplines and grades, and there is a trend of multi-disciplinary application (analysis in

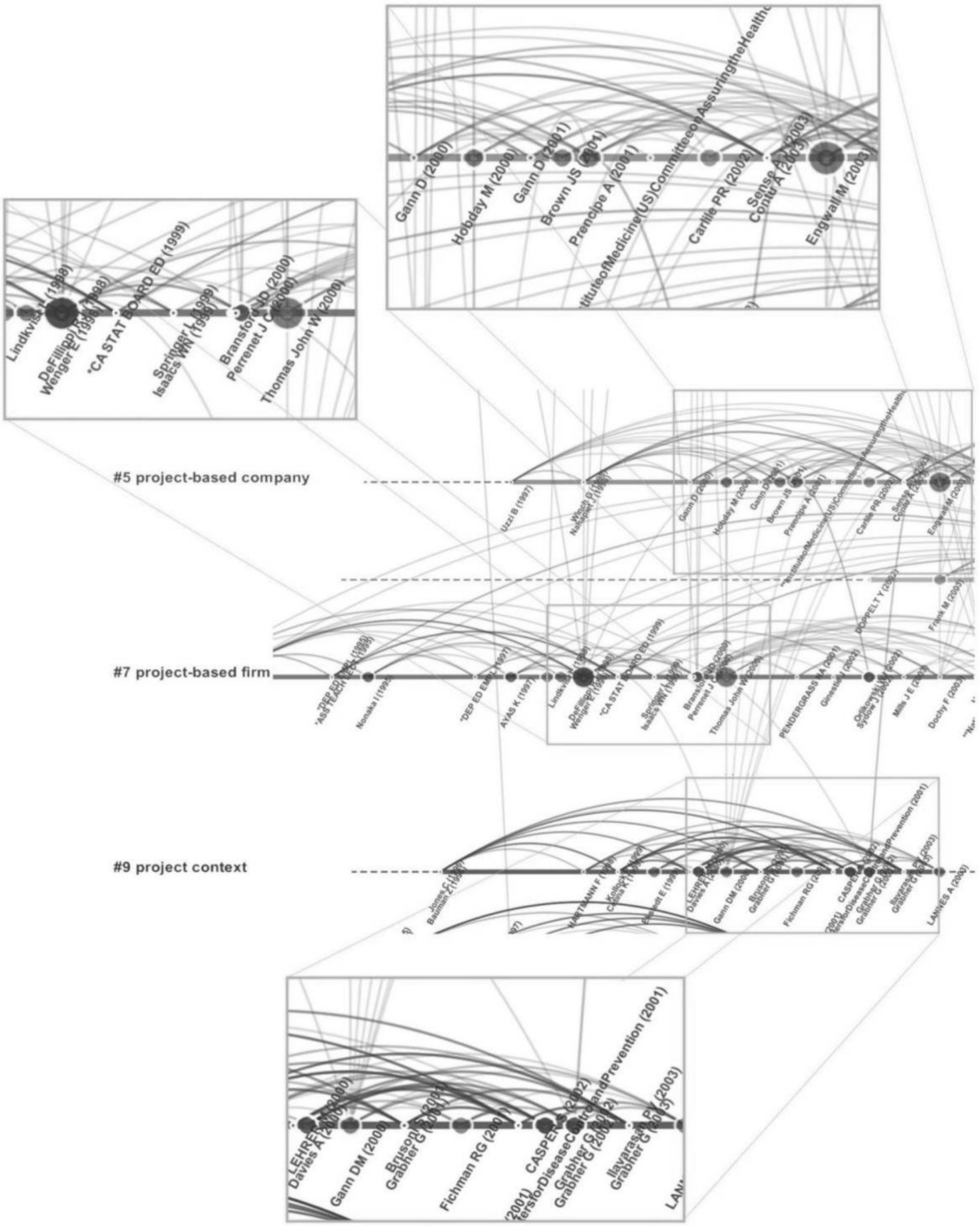

Fig. 7. High-impact members of Cluster 5, Cluster 7, Cluster.

details see in Stage III). Second, in the research related to the project, researchers have a strong interest in the organization and management of project. Third, the social construction of knowledge, which has just started in the first stage, has become a research hotspot in this stage (Fig. 5). Table 6 lists the major articles related to social construction of knowledge.

The concept of PBL has a certain similarity with the notion of knowledge building [21]. The social construction of knowledge is determined by the extent that the student is able to draw upon

Table 6. Major citing articles to Cluster 6 on social construction of knowledge

Freq.	Burst	Author	Year	Journal	Title
15	7.20	Helle L	2006	*Higher Education*	Project-Based Learning in Post-Secondary Education – Theory, Practice and Rubber Sling Shots
8	3.20	ChanLin LJ	2008	*Innovations in Education and Teaching International*	Technology integration applied to project-based learning in science
7	3.43	Gulbahar Y	2007	*Journal of Research on Technology in Education*	Implementing Project-Based Learning And E-Portfolio Assessment In an Undergraduate Course
5	0	Rios ID	2010	*Procedia Social and Behavioral Sciences*	Project–based learning in engineering higher education: two decades of teaching competences in real environments
4	0	Hou HT	2008	*Interactive Learning Environments*	An Analysis of Peer Assessment Online Discussions within a Course that uses Project-based Learning

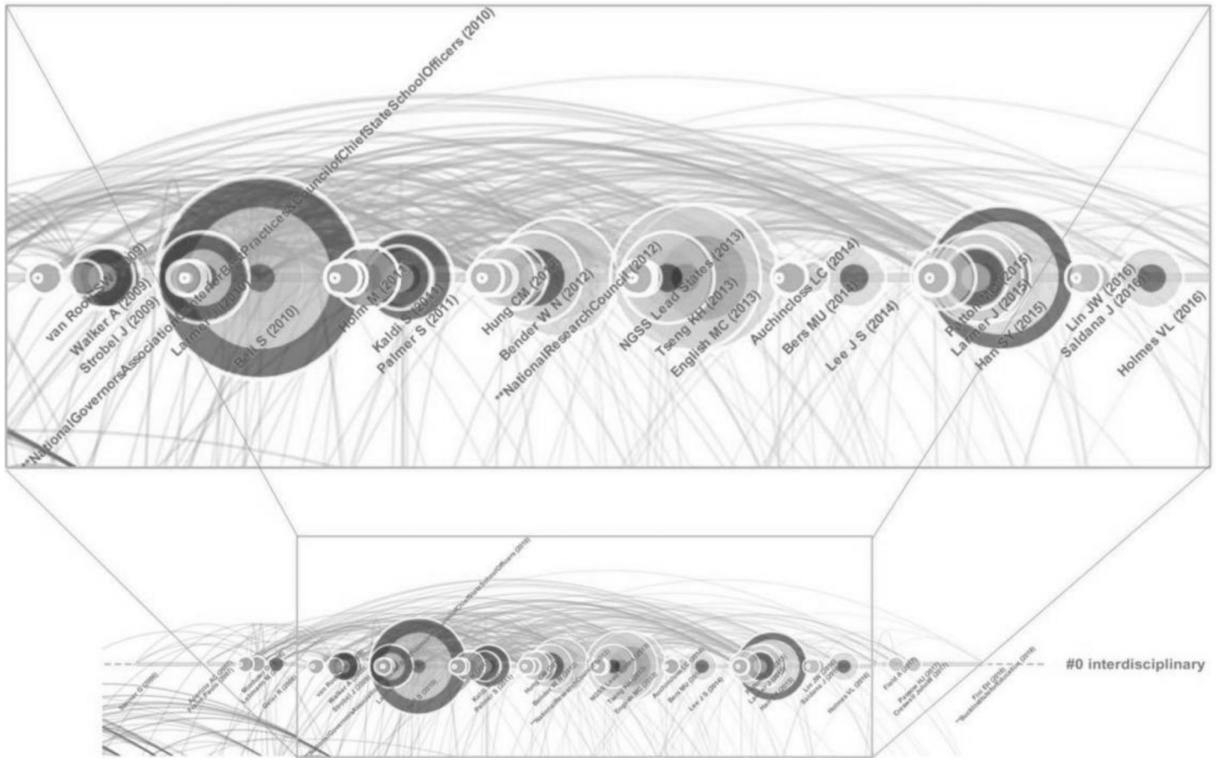

Fig. 8. High-impact members of Cluster 0.

vertical knowledge, not just horizontal knowledge, and PBL can be described as involving both vertical learning (i.e., cumulation of subject matter knowledge) and horizontal learning (i.e., generic skills such as project management). PBL is one of the methods grounded in constructivism by supporting student engagement in problem-solving situations [22]. In PBL environment, students have a chance of learning by doing, enhancing their critical skills, and shaping their learning process through active learning and interaction with the teaching staff, their teammates, experts, and other students in the course [23]. Students in a PBL environment deal with real-life problems, which may result in permanent knowledge. Following the trends in psychology of knowledge, PBL is considered as the most suitable means of achieving social competence that integrates knowledge, skills and values [24]. As such, methodologies like cooperative PBL and problem oriented PBL (POPBL) are explored to promote the students' knowledge construction and education for sustainable development [25].

3.3.3 Stage III: Application Period (2010–2021)

Cluster 0 is the largest one with 138 literatures. The research topic of Cluster 0 is interdisciplinary, which focuses on dealing with complex problems

Table 7. Major citing articles to Cluster 0 on interdisciplinary

Freq.	Burst	Author	Year	Journal	Title
50	19.39	Bell S.	2010	*Clear House*	Project-Based Learning for the 21st Century: Skills for the Future
23	4.71	English M.C.	2013	*Interdisciplinary Journal of Problem-Based Learning*	Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning
20	4.14	Han S.Y.	2015	*International Journal of Science and Mathematics Education*	How science, technology, engineering, and mathematics(STEM) project-based learning(PBL) affects high, middle, and low achievers differently: the impact of student factors on achievement
18	5.72	Tseng K.H.	2013	*International Journal of Technology and Design Education*	Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment
13	5.91	Larmer J.	2010	*Educational Leadership*	Seven essentials for project-based learning

of real-world cases from an interdisciplinary perspective. It also emphasizes that students require creativity, social competencies and specific communication skills in order to cope with the dynamic change that characterizes the developments in most facets of society and nature (Table 5). We analyze the intellectual base and development process of interdisciplinary in PBL based on Fig. 6 and Table 5. Steiner proposed that the implementation of interdisciplinary projects in University of Graz integrated research and teaching activities, which led to the self-regulated mutual learning process between the actors concerned and promoted the sustainable development of higher education [26]. However, there were no remarkable citation counts or bursts until ''NGSS'' defined the cross-disciplinary concepts for all k-12 students in the Next Generation Science Standards for all k-12 students. There is full of high-impact contributions-large citation treerings and periods of citation bursts colored in red since 2010. Two high-impact research topics have gradually formed. One is how to improve students' skills for the 21st century in K-12 Education, the other is how to improve students' employability through STEM education.

As for K-12 education, one article from Bell (2010) is cited most (50) and has the most bursts (19.39). Bell concluded that PBL is a key strategy for solving real-world problems. Social learning exposes students to unknown problems, which forces them to seek interdisciplinary knowledge to complete their subjects, thus improving their skills in self-reliant, collaboration, negotiation, planning and organization [27]. Instructional strategies, assessment methods, and detailed instructions strongly support interdisciplinary cooperation in PBL that fosters 21st century skills and innovative thinking. Gold standard and seven essentials for PBL regulate interdisciplinary development in PBL [28]. Seven crosscutting concepts of the framework provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world, and help students develop a cumulative, coherent, and usable understanding of science and engineering [29].

STEM has become a research hotspot in the field of PBL since it was put forward by the United States in 2006. STEM is particularly suited for PBL because of the natural overlap between the fields of science, technology, engineering and mathematics. STEM (PBL) is perfectly suited for developing students' conceptual knowledge, because well-designed PBL is inherently interdisciplinary and collaborative in nature. STEM (PBL) facilitates the integration of content from different subject areas. STEM learning within the PBL should be seen as a ''meta-discipline,'' in which curricular areas are integrated in a way that promotes analysis and deep understanding. Researchers investigated whether participating in STEM (PBL) activities affected students who hand varied performance levels and found that combining PBL with STEM can increase effectiveness, generate meaningful learning and influence student attitudes in future career pursuit [30]. In another study students reported that their experiences participating in interdisciplinary STEM (PBL) helped them to better understand the world around them [31]. STEM learning should be seen as a ''meta-discipline,'' in which curricular areas are integrated in a way that promotes analysis and deep understanding. The combination of STEM and PBL is a student driven, interdisciplinary, collaborative, and technology based instructional strategy, and focusing on learning is a dynamic process, which connects K-12 and post-secondary education and addresses the future workplace learning needs. However, the popularity of research on STEM and interdisciplinary has declined in recent years ,

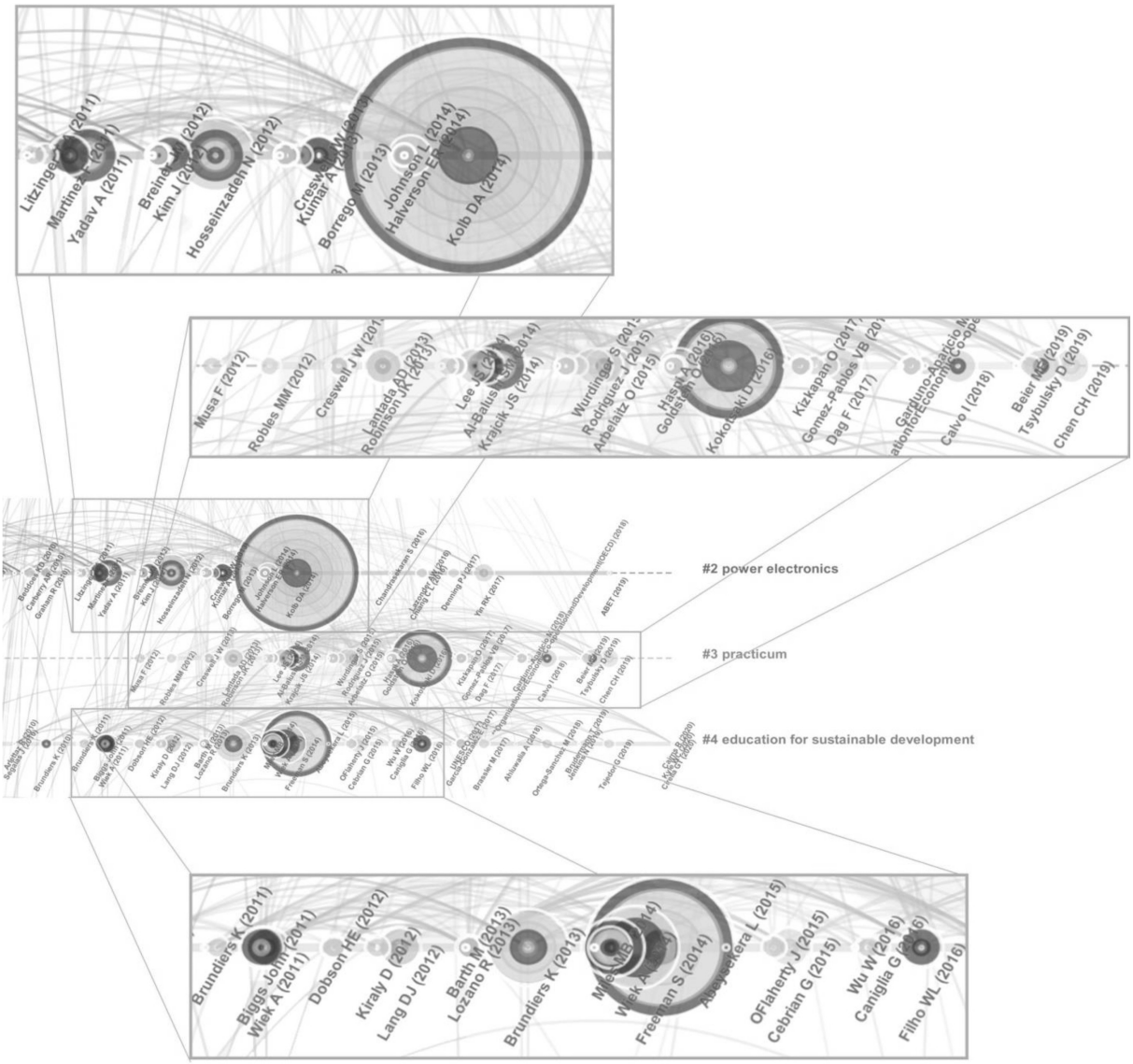

Fig. 9. High-impact members of Cluster 2, Cluster 3, Cluster 4.

Table 8. Major citing articles to Cluster 2 on power electronics

Freq.	Burst	Author	Year	Journal	Title
67	4.88	Kolb D.A.	2014	*Perspectives on thinking, learning, and cognitive styles*	Experiential learning theory: Previous research and new directions
15	4.73	Hosseinzadeh N.	2012	*IEEE Transactions on Education*	Application of Project-Based Learning (PBL) to the Teaching of Electrical Power Systems Engineering
12	3.46	Yadav A.	2011	*Journal of Engineering Education*	Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course
10	3.94	Borrego M.	2013	*Journal of Engineering Education*	Team Effectiveness Theory from Industrial and Organizational Psychology Applied to Engineering Student Project Teams: A Research Review
9		Halverson E.R.	2014	*Harvard Educational Review*	The Maker Movement in Education

and scholars tend to research on practical and sustainable development [32].

Cluster #2 is the third largest one as shown in Fig. 5, which indicates the implementation of PBL has gradually spread to the field of engineering education in higher education, especially the

major of the power electronics. Table 6 lists major citing articles on power electronics. Scholars in this field no longer regard that PBL was applied to individual course within a program. Instead, PBL is applied to multiple courses and combined with other learning methods throughout the whole program. Learning methods such as experiential learning [33], inquiry learning, problem-based learning and case-based teaching [34] are often integrated into PBL to improve students' professional practice ability. Problem- and project-based learning (PPBL) which combines the advantages of PBL and Problem-based learning, is proved to be effective in cultivating students' sustainable learning ability [35]. A hybrid form of PBL [36], which combines learning through projects with delivering essential knowledge via short lectures, is more effective in delivering both technical content and generic professional skills in a specialized course. Furthermore, rubrics used for the different aspects assessed for implementation of PBL [37], multidisciplinary projects based learning are more appealing to students [38].

Practicum (Cluster #3) activities are a very important and vital component of science education. Fig. 9 shows that practicum has become a hot spot of PBL research in recent years, due to the fact that a practicum-based project can improve students' learning outcomes, including self-learning, creativity, problem solving and teamwork [39]. Researchers affirmed the positive role of active learning in practicum-based learning in project from quantitative and qualitative dimensions. A survey shows that projects promote active participation by students (95%), motivate them to learn (96%) and help them to acquire various curricular skills (90%) [40]. Other survey results show that practicum-based project learning promotes students' active participation, encourages their motivation [41], and improves students' satisfaction. They not only acquire better technical training and results, but also develop soft skills [42], transversal skills [41] and life skills [43]. However, implementing practicum-based project learning raised several challenges: a lack of support from school management teams [40]; inadequate provision of technological tools [44]; the tension between the quality of learning and the scope of the course content [45]. Therefore, six key recommendations, namely student support as well as teacher support, effective group work, balancing didactic instruction with independent inquiry method, assessment emphasis on reflection, self and peer evaluation, and student choice and autonomy are considered to be essential for the successful implementing practicum-based learning [46].

Education for sustainable development (ESD) (Cluster #4) is an educational approach that emphasizes the acquisition of a broader range of skills or attributes within the taught curriculum, which should lead to a widening of their chances of the employment market [47]. UNESCO's calls for building the capacity to turn knowledge into action for sustainable development; it also calls for curricula to be reoriented to meet this goal. Many institutions are looking for suitable learning methods to develop sustainable programs, among which School of Sustainability in Arizona State University is the most prominent and has made a milestone contribution to ESD. As shown in Fig. 9, Brundiers and Wiek have a lot of results on PPBL and make a great influence in the field of ESD [35]. Wiek synthesized the following key competencies in sustainability: systems-thinking competence; anticipatory competence; normative competence; strategic competence; and interpersonal competence. To achieve the key competences, framework for PPBL courses in sustainability address real-world sustainability problems, which are considered powerful educational settings for building students' sustainability expertise [48]. Moreover, Wiek put forward improvement strategies for the identified challenges and provided guidance for design and redesign of PPBL courses [49]. The research results show that successful PPBL programs for ESD requires the top-down commitment from the administration, bottom-up drive from students and interested faculty and openness on behalf of the project-partners.

Though the key clusters are discussed independently above, they are closely related with each other. The links among nodes are not only horizontally related, but also staggered among vertical clusters (Fig. 5). Based on the discussion above, clusters (#0, #2, #3) are prerequisite for cluster #4. Students with interdisciplinary backgrounds actively engage in practicum-based project learning, dealing with real-world problems is basically essential for sustainable development in education. In this sense, PBL aims to help students for lifelong learning and cultivate success skills for 21st century to better meet the future challenges.

3.4 Intellectual Base of PBL Research in Mainland China Journals

In order to better understand the differences of PBL research in and outside mainland China, and to build a bridge between them, we analyze the hotspots in the development of PBL research in mainland China. First, we plotted time zone view of PBL (Fig. 10) by running CiteSpace with 521records from CNKI database. Visualization of the time zone can clearly show the evolutionary process of knowledge over time [50]. The font size and node

Table 9. Top 10 keywords with the strongest citation bursts

Keywords	Strength	Begin	End	2001–2021
项目式学习 (PBL)	19.27	2003	2021	
应用 (Application)	2.38	2009	2010	
实践教学 (Practical Instruction)	1.98	2009	2012	
高职院校 (Higher Vocational College)	2.62	2011	2014	
协作学习 (Collaborative Learning)	2.45	2014	2015	
翻转课堂 (Inverted Classroom)	2.12	2014	2016	
STEM	1.43	2016	2019	
创客教育 (Maker Education)	1.29	2016	2016	
核心素养 (Core Competence)	2.26	2017	2018	
新工科 (Emerging Engineering Education)	1.85	2020	2021	

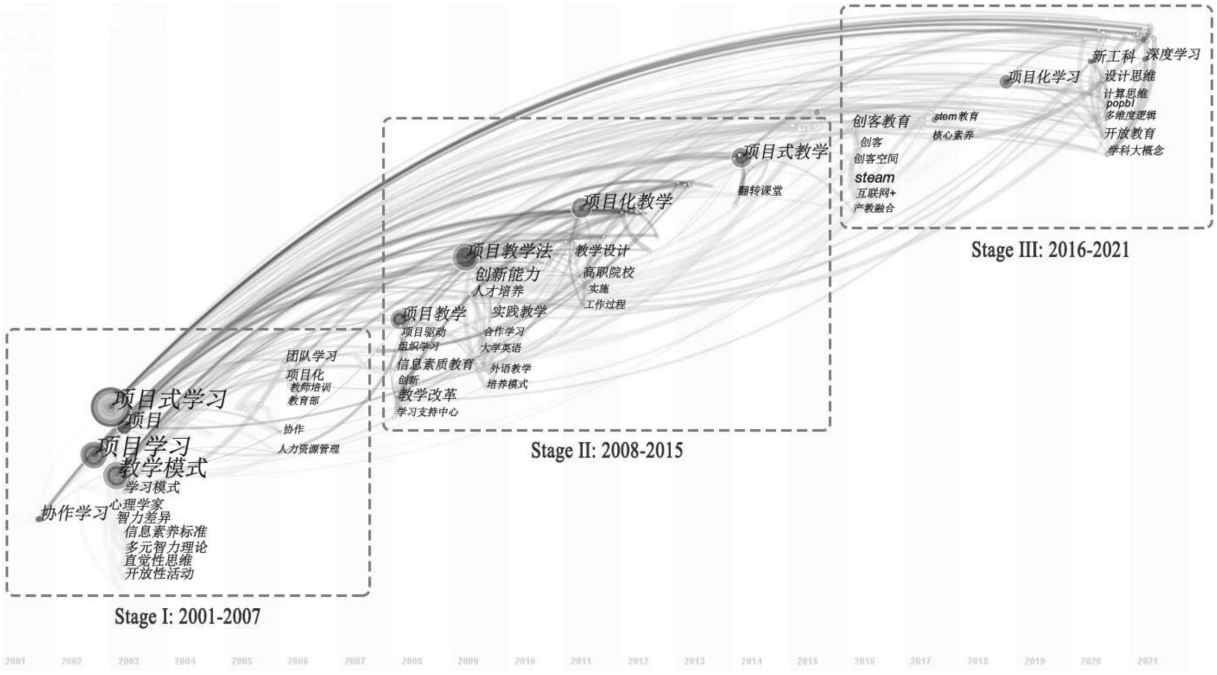

Fig. 10. Time zone view of PBL keywords in mainland China.

size denote the frequency of keywords. The links of nodes indicate the inheritance of research. Second, by running CiteSpace, Table 7 was plotted where lists the top 10 keywords with strongest citation bursts in 2000–2021, which could reflect hot topics and indicate frontier topics. Third, combined with the visualization of the time zone and burst keywords, the next part will establish the evolution of PBL in mainland China.

3.4.1 Stage I: Embryonic Development Stage (2001–2007)

PBL was first introduced into mainland China in the late 1990s, so researchers explored PBL at the beginning of this century and it is relatively conservative. Only keywords of PBL appear in Table 9, which indicates that PBL research is at embryonic stage. The application of PBL in mainland China was not in schools at first, but in enterprises to improve the cooperation skills and practical ability of employees [51]. By reading the literature and interpreting Fig. 10, we find that researchers focus on the following three aspects at this stage. 1) the role of PBL, such as teamwork ability and the promotion of enterprise human resource management. 2) the operation and implementation process of PBL, such as teaching mode, learning mode, technology and curricular reform [52] and organization form of PBL. 3) the background and theoretical basis of PBL, such as psychological theory, multiple intelligence theory and constructivism.

3.4.2 Stage II: Steady Development Stage (2008–2015)

The exploration of PBL at embryonic stage verified its feasibility and effectiveness in the practice course

teaching. In addition, (National Medium- and Long-Term Educational Reform and Development Guideline (2010–20) 2012) put forward the plan of promoting quality education reform, vocational education mode reform, lifelong education system and mechanism construction, and excellent engineering education and training plan [53]. Correspondingly, PBL appeared in different educational stages and disciplines, and was fully applied during 2008–2015. Vertically, it ranged from K-12 education to secondary education, from higher vocational colleges to graduate education [54]. Horizontally, the subjects involved included science, engineering, technology, mathematics, medicine, English and design [55], etc. Table 9 lists three keywords with strong citation burst, namely, ''application'', ''practical instruction'', ''higher vocational college'', ''collaborative learning'' [40], and ''inverted classroom'', which indicate that hotspots of PBL has extended to instruction strategy, instruction design, implementation process, practical instruction, learning motivation, etc. Fig. 10 defines that PBL has made contribution to the development of students' core ability, including problem-solving, innovation, and cooperation, which make up for the lack of students' professional ability in their careers [56]. Meanwhile, PBL is mainly implemented in the field of foreign language instruction [57]. Surveys show that more instruction methods and techniques have been integrated into PBL, and flipping classroom [58]is of great interest to educators. In a word, PBL research is still the center of the literature. Among them, the instruction mode, organization form, instruction evaluation and technical means are the main research directions at this stage.

3.4.3 Stage III: Diversified Development Stage (2016–2021)

The long-term implementation of PBL in education proves that PBL plays a significant role in improving students' practical and innovative ability in mainland China. Therefore, educators seek more instruction methods for developing students' core competence and higher-level ability. The 13th Five-Year Plan [59] clearly pointed out that it is necessary to make effective use of information technology to promote the construction of ''public innovation space'', and explore new educational modes such as STEM education and maker education (Table 9). Combination PBL with Maker education/STEM education has become an important way for educators to train more students with a strong sense of information and innovation, develop digital learning habits, attach importance to information security, and abide by the ethics and laws and regulations of the information society. STEM education and maker education in the project tend to point to the solution of real situation problems and devote themselves to cultivating students' high-level ability [60]. However, there are some differences between them. Maker Education tends to ask students their own questions, rather than asking all students to explore the same questions [61]. It emphasizes that students design and make their own works or products in order to help students turn their ideas into reality. In contrast, STEM education emphasizes the integration of different disciplines (science, technology, engineering and mathematics), and trains students to think in a multi-disciplinary way to solve problem comprehensively [62].

The Emerging Engineering Education Policies [63] in 2017 has accelerated the development of emerging industries, which puts forward higher requirements for high-quality compound new engineering talents with strong practical ability and strong innovation ability. Teaching reform is the first to bear. Educators boldly try to use the O2O-IPBL [64], progressive PBL [65], and from 1.0 to 3.0 advanced PBL, in order to the depth of the project learning. Some scholars have proposed to train students' design thinking, calculation thinking and multi-dimensional logical thinking ability in PBL [66], so as to realize interdisciplinary education and develop students' thinking. Based on the discussed above with Fig. 10 and Table 9, when STEM education or maker education is integrated into project, PBL will become more effective in developing students' open thinking and advanced ability, rather than PBL running alone.

4. Discussion

This paper reviews the development of PBL in the past 22 years by analyzing the bibliometric indicators of publications in both mainland Chinese journals and internationals from 2000–2021. Some useful results with the statistical information of various items (e.g., publication trends, countries/regions, institutions, journals and references) are shown. However, the analysis results above show that there are some differences in PBL-related research in and outside mainland China as follows:

(1) *Attributes of institution.* Research institutions in mainland China are homogeneous, mainly educational institutions, while almost all the institutions in the world are comprehensive universities. The research on PBL in mainland China is limited to certain disciplines and has not been widely spread and applied in many disciplines.

(2) *Research development and research hot spots correspond to each stage.* Since the last century, PBL has appeared and been studied in international

journals. Therefore, we had studied the theoretical construction and background of PBL, and its application in K-12 education before 2003. After that, PBL was applied in the whole field of education, from K-12 to undergraduate and even graduate students. The research focuses on how students integrate into society and construct social knowledge through projects, and how to integrate STEM education, problem-based learning, network technical support, student evaluation and other technologies and means, so as to cultivate students' multidisciplinary knowledge and sustainable development ability. However, the PBL research started in mainland China was relatively late, and before 2015, its implementation and research were conservative, which was mainly used in teaching reform and widely used in K-12 education. Until 2016, the research on PBL kept pace with the international research, and the international popular teaching methods can be found in mainland Chinese journals.

(3) *Discipline application.* PBL is widely applied to science courses in K-12 education and technology courses in higher education in the world. Although PBL took part in higher education courses in mainland China, these courses are mainly English teaching.

In short, there are still some deviations in the research on PBL in and outside mainland China based on the above analysis. Therefore, we draw on our findings to offer the following suggestions to researchers and educators, so that they can optimize various resources and strengthen research on PBL inside and outside mainland China. We believe that such efforts may help relevant research bring more advantages to education in mainland China and outside.

First, we believe that researchers should conduct in-depth research into the development of PBL from the following aspects: (1) *Students-centered comprehensive development ability.* Students solve problems collaboratively in real environment, and develop skills of cooperation and sustainable learning. (2) *Teachers' professional development.* Colleges and universities provide platforms and financial support for improving teachers' professional ability and promoting the development and transformation of teachers' role in the new era. (3) *Technical guarantee.* We suggest that we should make full use of technology to build a PBL environment and create a learning environment. We also encourage students to explore more virtual network technologies as query tools, and use multimedia technologies to display results. (4) *Improvement of evaluation.* Implementers and institutional researchers should take all-round and whole-process evaluation, including the evaluation of project organization and process mechanism by project team members, teachers and enterprise project managers. We also believe that it is more reasonable to combine quantitative and qualitative evaluation methods.

Second, we believe that more efforts to bridge differences of PBL research in and outside mainland China should be undertaken. International cooperation in projects links them together. Whether it is a small-scale cooperation of similar professional projects between international education partners at the beginning, or a large-scale cross-professional cross-border project planning cooperation in the later stage, institutions needs to provide sufficient financial support and grant opportunities to build platforms for international cooperation and to support cross-border projects. For example, with the help of IEARN [67], Taiwan has carried out many international collaborative project learning, including international projects involving primary and secondary school languages courses, international project cooperation integrating social practices, and international projects in the field of higher education. The purpose of international cooperation project is to allow students to develop their ability to adapt to the future society by participating in the project. The cooperation of projects in PBL has shortened the research gap in this field between in and outside mainland China, and the publication of the results has also contributed to the field of education.

Finally we would encourage institutions in and outside mainland China to organize academic conferences on PBL, and advocate researchers to co-organize academic dialogues on PBL, so as to establish international connections and create opportunities for cross-border cooperation. These may discuss and solve the research issues of common concern in implementation of PBL. We also believe that international journals can provide such a platform to promote relevant dialogues, promote cooperation between international institutions, and raise the awareness of researchers, especially the awareness of researchers in mainland China on each other's work, and make their research international.

5. Conclusion

PBL is one of the instruction methods to promote the all-round development of students' ability of collaboration, communication and expression, critical thinking and problem solving, project management and self-management, creativity and innovation. This paper exhibited a visual and scientometrics review of PBL in detail covering

every related article from WoS database and CNKI from 2000 to 2021.

First, this paper identifies the development trajectories and topical trends of PBL research in mainland Chinese and international journals by analyzing publication trends, core countries/regions, core institutions, and core journals. The results show that the number of publications on PBL has been increasing, especially in the international journals. The results also suggest that in international journals, the number of PBL-related articles published is mainly from European and American countries, among which the United States ranks first and the core institutions account for half of them, making the greatest contribution. Although mainland China ranks third with 140 articles published in international journals, it has not yet formed core institutions with outstanding contributions in the world, and mainland China has insufficient influence in international journals.

Second, according to the timeline of visualization of major clusters of international journals and the time zone view of the most explosive keywords and citations in Chinese mainland journals, this paper expounds the knowledge base and evolution process of each field at each stage. There are three stages in the development of international journals. Stage I: Early Period (–2003) focuses on the application of PBL in middle school science. Stage II: Transition Period (2004–2009), researchers pay attention to the organization form, management and knowledge construction of project learning method of PBL. Stage III: Application Period (2010–2021) is the outbreak of PBL application, which is applied to electric power, practical disciplines and the cultivation of students' sustainable ability. Meanwhile, the development of PBL in mainland China can be divided into three stages. Stage I: Embryonic Development Stage (2001–2007), the purpose of PBL application in mainland China is to improve the employees' cooperation skills and practical ability. Stage II: Steady Development Stage (2008–2015), PBL is widely used. Vertically, it extended from K-12 to secondary education. Horizontally, disciplines such as science, engineering, technology, mathematics, medicine, English, and design are all involved. Stage III: Diversified development Stage (2016–2021), PBL is combined with maker education/STEM education, and educators seek more teaching methods to cultivate students' core competence and higher-level competence.

Finally, this paper finds that different research issues are paid attention to from different perspectives in and outside mainland China, but there is little cross-border research cooperation between them. Some suggestions are put forward for discovery researchers and educators, including in-depth study of PBL hot topics, introduction of international projects and encouragement of academic exchanges. In order to better establish international contacts, create opportunities for cross-border cooperation and promote the development of PBL.

The study has several limitations. First, we only reviewed the journal articles related to PBL research in Web of Science (WoS) in international and CNKI in mainland China. Therefore, related articles in other databases may be missed, especially the survey results of leading researchers and institutions in PBL research field. Second, while Citespace was used to aid this study, some potentially representative literature was omitted due to the low number of citations. Finally, because this study examined PBL development over time, it did not delve deeply into PBL in a specific field, discipline, or profession. These are welcome to be highlighted and exchanged by colleagues over time. In conclusion, we hope that this study can serve as an inspiration and anticipate that future research on PBL will become more in-depth both domestically and internationally.

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Shuang Lin was born in 1983. She received an MS degree in Art & Design from Kunming University of Science and Technology, China in 2008. She is currently an Associate Professor with the School of Art & Design, Taizhou University, China. Her primary research interests include product/service design and product sound design. E-mail: lina0518@tzc.edu.cn

Zhengtang Tan was born in 1986. She received the PhD degree in design science from Hunan University, China. She is currently the master supervisor in Hunan Normal University, China. Her research interests focus on the complex product design. E-mail: tanzhengtang@hunnu.edu.cn

Wenping Guo was born in 1978. He received an MS degree in computer science from Southwest Jiaotong University, China in 2005. He was a visiting scholar at Jacksonville State University, USA from February 2012 to June 2012. He is currently a Professor with the Department of Computer Science, Taizhou University, China. His research interests include machine learning and multimedia content analysis. E-mail: guowp@ tzc.edu.cn