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Bibliometric Analysis: Collaboration Networks in Discovery Learning Research

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Abstract: This research identifies publications related to Discovery learning. Discovery learning is a learning model that encourages active learning in students through self-discovery and research so that the results achieved are long-lasting and difficult to forget. This research aims to identify and analyze articles researching Discovery Learning that have been published in several reputable international journals published in the 2014-2023 period, which was carried out using bibliometric studies. Bibliometric analysis produced four findings: publications about Discovery Learning in Scopus-indexed journals have been in a fluid and balanced pattern every year for the last ten years; 328 of the ten journals producing the most articles have been published. The top-ranked journal published 15 articles, and the tenth-ranked journal published five articles; The most citations occurred in articles published in 2020 with a total of 1101 citations. The most cited article was written by B.R. Goldsmith with 241 citations; The author's keywords that are most frequently used in the top three are discovery, machine, and machine learning.

Keywords: Bibliometrics; Discovery learning; Scopus database

Introduction

The development of human character and self-maturation is the result of education which allows humans to develop their potential, abilities, and skills. There is a recognized need to educate children who can solve problems, make intelligent decisions, think critically and innovatively, and work hard both individually and in groups. Education that improves the quality of Human Resources (HR) is needed to achieve character and personal maturity and ensure sustainable national development. The development of human character and self-maturation is the result of education which allows humans to develop their potential, abilities, and skills. There is a recognized need to educate children who can solve problems, make intelligent decisions, think critically and innovatively, and work hard both individually and in groups. Education that improves human resources is needed to achieve the character and personal maturity and ensure sustainable national development (Mensah, 2019; Hariram et al., 2023).

Education as an investment in the future is meaningless if it is not accompanied by continuous improvement, development, and learning innovation. One effort to achieve this goal is to always look for and find breakthroughs or innovations in learning that have an impact on introducing the nation's character and cultural values (Haleem et al., 2022; Serdyukov, 2017). Learning activities require active learning, namely joint participation between teachers and students. Learning activeness is student activity or teaching and learning activities at school and outside school that support student success (Buckley & Lee, 2021). Forms of student activity in learning can be seen from student involvement in the learning process, such as participating in carrying out assignments, being involved in discussing the problem-solving process, asking friends or teachers if they do not understand the material, and being able to present report results (Sinaga et al., 2023).

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Realizing active learning requires a learning model that can train students' independence and is based on technological advances and adapted to current developments so that students can learn and discover new concepts (Kim et al., 2019; Lodge et al., 2018). According to Baričević & Luić (2023), an active learning environment is one where students can develop new ideas. Applying the right learning model can influence student success in the learning process. The learning model that can be used is discovery learning, discovery learning aims to provide opportunities for students to formulate problems, test hypotheses, draw conclusions, and present them (Jayanto et al., 2019; Pedaste et al., 2015).

This research aims to identify publications related to Discovery learning in educational research. Bibliometric analysis is used in this research to explore the characteristics of Discovery learning publications in education and related factors as well as to analyze trends in research focus in this field (Wu & Chou, 2023). With knowledge about Discovery learning, research was carried out based on the problem formulation as follows.

Method

This research uses a study bibliographic design using a systematic and explicit mapping method. Bibliometric analysis is a study of bibliographic analysis of scientific activities, which is based on the assumption that a researcher carries out research and must communicate the results to colleagues. This will provide progress and development of knowledge if researchers carry out joint activities to study specific research topics (Darling-Hammond et al., 2020). Bibliometric analysis has a role in evaluating scientific research results and mapping scientific fields, tracking the development of new knowledge in certain fields (Rejeb et al., 2023). Meanwhile, the bibliographic study stages use four stages as carried out by José De Oliveira et al. (2019), and consist of search procedures; bibliographic filter; bibliometric completeness, and; bibliometric analysis.

Search Procedure

The first step is the identification process, using Publish or Perish (PoP) software as an application and using the PoP application to search for references. Researchers enter keywords in searches on the Scopus database. Scopus is the largest collection of literature summaries in the world, with citations that provide abstracts from various peer-reviewed scientific literature and research. Scopus can help researchers effectively track, analyze, and visualize research (Ullah et al., 2022; Raslan, 2023).

The keyword entered is Discovery Learning. From the results of this identification, publication data was obtained for 328 articles (Brennan et al., 2021). Several criteria were established for all bibliographies included in the analysis (Snyder, 2019), covering three aspects: Journals with bibliographic type only; The title of the article must include "Discovery Learning"; The search year was limited to the period 2014 to 2023 (the last 10 years). PoP searches in the Scopus database are limited to a maximum of 200 articles in one search. Then the data was processed and analyzed using Microsoft Excel to obtain tables and graphs (Munawar et al., 2020). Figure 1 shows the bibliographic search process in the PoP application.

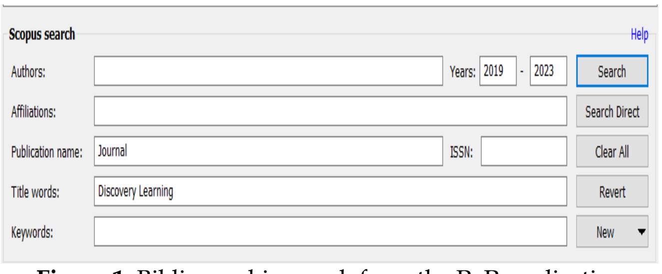


Figure 1. Bibliographic search from the PoP application

Bibliography Filter

Table 1. Bibliography Selection Results

Year of Publication	Inclusion	%	Exclusion	%	To tall
2014	7	100	0	.00	7
2015	10	90.90	1	0.10	11
2016	10	76.92	3	23.08	13
2017	11	55	9	45	20
2018	24	57.14	18	42.86	42
2019	27	39.71	41	60.29	68
2020	55	64.70	30	35.30	85
2021	52	57.14	39	42.86	91
2022	49	89.09	6	10.91	55
2023	83	89.25	10	10.75	93
Total	328		157		485

References are selected and ranked based on several criteria. In other words: providing context for discovery learning; using English; published by an established or reputable bibliographic database publisher. Each bibliography included or excluded from the bibliographic analysis process is verified by tracking it in the Scopus database extracted from the PoP application. The reference types selected are article types only and those published in journals. Several reference lists that appeared in the PoP application search process were not selected because they were conference articles, errata, notes, editorials, reviews, clones, or articles without an abstract.

Initial search results using the PoP application produced a list of 485 references which were categorized into 328 selected reference lists. 157 reference lists were not selected because they did not meet the specified criteria. Table 1 shows the total number of references each year resulting from searches via the PoP application. This table shows that several articles were published and several articles were not published because they did not meet the requirements.

Bibliography Completeness

To perform filtered bibliographic analysis, metadata is reviewed and finalized. This research includes things analyzed such as article title, author's name, institution and country of publication, abstract, author's keywords, article link, publisher, and year of publication. Once the metadata is complete, bibliographic analysis is performed.

Bibliographic Analysis

Bibliographic analysis was carried out based on the following five aspects: publication trends, journals that published the most articles about Discovery Learning, most cited articles, Journal Keywords - Most Cited Articles Frequently Used in Discovery Learning. The VOSviewer application is used to carry out bibliographic analysis and visualize the results of bibliographic analysis. VOSviewer is used to process large amounts of data efficiently and provides a variety of visualizations, analyzes, and observations.

Result and Discussion

The discovery learning model in learning can encourage students to carry out investigations to find scientific truth, rather than being invited. Discovery learning is learning that occurs when students manipulate, organize, and change information to discover new information. When learning to discover, students can make conclusions (combinations), formulate hypotheses, find the truth using inductive or deductive processes, make observations, and formulate problems (Collins & Stockton, 2018). The use of learning models is very important to arouse enthusiasm and motivation to learn and encourage students to play an active role in the learning process (Ariftian et al., 2021; Getie, 2020). The discovery learning model is expected to facilitate understanding of the learning content being taught, improve the quality of the subsequent learning process, and in turn improve student learning outcomes (Muhayati et al., 2023). Discovery learning is a learning model that encourages active learning in students through self-discovery and research, so that the results achieved are long-lasting and difficult to forget (Sewagegn & Diale, 2019). The development of discovery learning improves students' thinking and is proven to be effective, practical, and effective. Effectiveness of the discovery learning model: found to improve student learning outcomes compared to direct learning (Payu, 2023). The application of this model turns teachers into providers and supporters of student learning activities in the classroom, thereby enabling students to discover new knowledge on their own by using the Teacher's Guide. With the development of discovery learning model devices, it will increase. Another result of the invention learning model is that the ability to pose problems will increase, as will research results (Chusni et al., 2020).

Publication Trend Analysis

The trend of publications related to Discovery Learning from 2014 to 2023 is shown in Figure 2. A total of 328 publications are grouped by year of publication which can be seen in Figure 2.

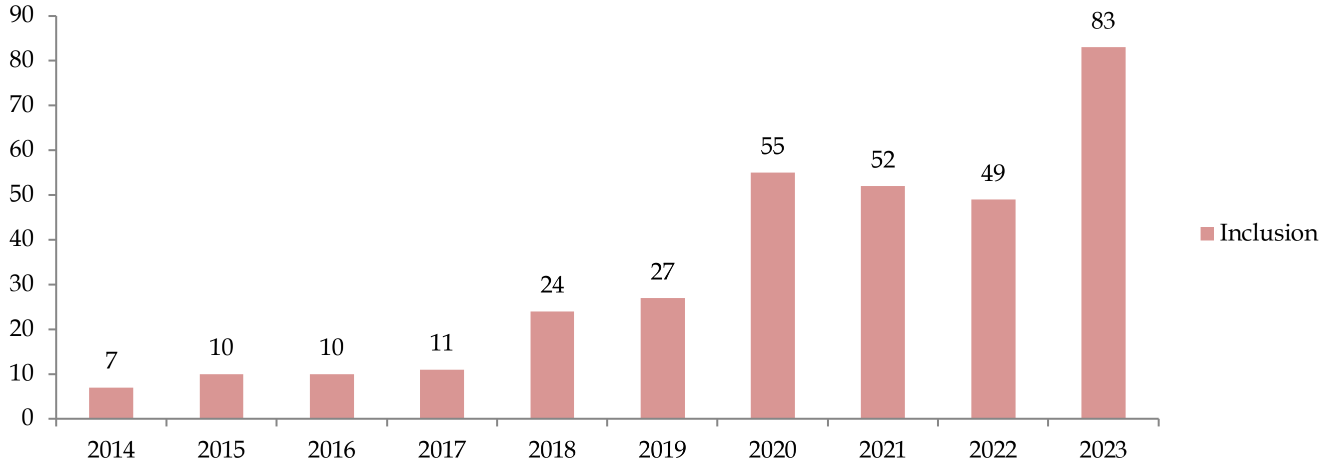


Figure 2. Publication trends per year

From Figure 2 it can be seen that in 2023 there will be 83 articles published, this is the highest number of publications compared to other years. Looking at the trend line, it can be seen that publications have increased every year from 2016 to 2020, although the number of publications from 2014 to 2023 has not changed much. A rapid increase in the number of publications occurred in 2022 to 2023, increasing from 49 in 2022, and in 2023 to 83, which means the increase doubled from 2019 to 2020.

Analysis of Various Journals

Table 2. Journals that publish the most articles about Discovery Learning

Journal	Number of Articles
Journal of Chemical Information and Modeling	15
Journal of Physical Chemistry Letters	12
International Journal of Molecular Sciences	11
Journal of Materials Chemistry A	10
Journal of Biomolecular Structure and Dynamics	8
International Journal of Instruction	7
Journal of Physical Chemistry C	7
International Journal of Emerging Technologies in Learning	6
International Journal of Scientific and Technology Research	6
Journal of Medicinal Chemistry	5

Table 2 shows the top 10 journals that publish the most articles about Discovery Learning. The Journal of Chemical Information and Modeling takes the top spot with a total of 15 articles. In second place is the Journal of Physical Chemistry Letters which published a total of 12 articles. The following journals in the 3-4 range published 11 and 10 articles respectively: International Journal of Molecular Sciences and Journal of Materials Chemistry A. Journals in the 5-10 position published fewer than 10 articles.

Citation Count-Based Analysis (Citation Rate per Year)

Figure 3 depicts the number of citations to articles regarding Discovery Learning. The quote pattern shows an up-down-up-down pattern. The increasing pattern occurred from 2017 to 2018, and 2019 to 2020. Meanwhile, the decreasing pattern occurred mostly from 2018 to 2019 and from 2020 to 2023. The most citations occurred in 2020 with a total of 1101 citations from 55 articles, and at least citations will occur in 2023 with a total of 98 citations from 83 articles. There has been no increase in the number of citations from 2020 to 2023.

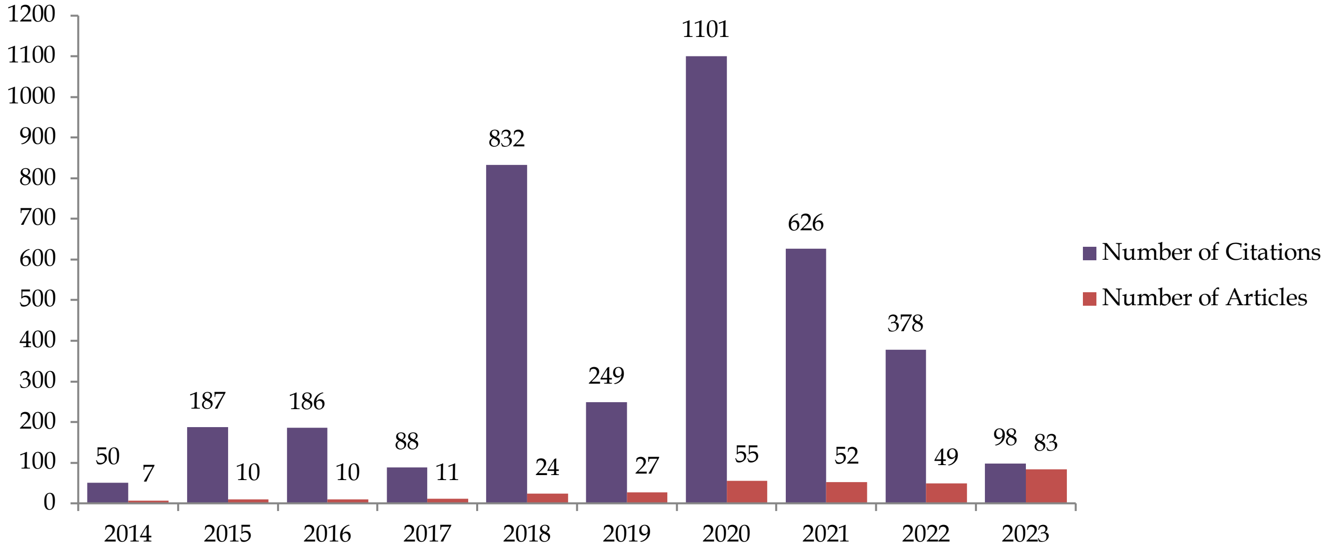


Figure 3. Number of Citations per Year

Figure 3 above shows that although there were only 24 articles published in 2018, there were 832 citations. This shows that papers published in 2018 have a significant impact on other research.

Ten Most Quoted Articles

Table 3 shows the 10 most cited articles regarding Discovery Learning. Most of the top quotes come from author B.R. Goldsmith with the title Machine Learning for heterogeneous catalyst design and Discovery published in 2018 with 241 citations, followed in second place by C. Cai with the article title Transfer Learning for Drug Discovery in 2020 with 149 citations. Third place by author J. Janet with the title Accelerating Chemical Discovery with Machine Learning: Simulated Evolution of Spin Crossover Complexes with an Artificial Neural Network in 2018 with 138 citations. The fourth and fifth sequences show quite high numbers, namely greater than 100 citations. The sixth to tenth positions show a fairly high number of quotations, namely more than 50 quotations.

Table 3. Highest Cited Articles

Writer	Article Title	Publication Year	Number of Citations	Journal Name
Goldsmith et al., 2018	Machine learning for heterogeneous catalyst design and discovery	2018	241	AIChE Journal
Goldsmith et al., 2018	Machine learning for heterogeneous catalyst design and discovery	2018	241	AIChE Journal
Cai et al., 2020	Transfer Learning for Drug Discovery	2020	249	Journal of Medicinal Chemistry
Janet et al., 2018	Accelerating Chemical Discovery with Machine Learning: Simulated Evolution of Spin Crossover Complexes with an Artificial Neural Network	2018	138	Journal of Physical Chemistry Letters
Mahmood et al., 2022	Machine learning and molecular dynamics simulation-assisted evolutionary design and discovery pipeline to screen efficient small molecule acceptors for PTB7-Th-based organic solar cells with over 15% efficiency	2022	113	Journal of Materials Chemistry A
Kennedy et al., 2015	Comparing Robot Embodiments in a Guided Discovery Learning Interaction with Children	2015	109	International Journal of Social Robotics
Guo et al., 2021	Machine-Learning-Guided Discovery and Optimization of Additives in Preparing Cu Catalysts for CO<inf>2</inf>Reduction	2021	73	Journal of the American Chemical Society
Spellings & Glotzer, 2018	Machine learning for crystal identification and discovery	2018	71	AIChE Journal
Legrain et al., 2018	Materials Screening for the Discovery of New Half-Heuslers: Machine Learning versus ab Initio Methods	2018	71	Journal of Physical Chemistry B
Ulissi et al., 2016	Automated Discovery and Construction of Surface Phase Diagrams Using Machine Learning	2016	69	Journal of Physical Chemistry Letters
Shmilovich et al., 2020)	Discovery of Self-Assembling π-Conjugated Peptides by Active Learning-Directed Coarse-Grained Molecular Simulation	2018	64	Journal of Physical Chemistry B

Table 3 lists the 10 articles with the highest citations. Where in 2015 there was 1 article, in 2016 there was 1 article, in 2018 there were 4 articles, in 2020 there were 2 articles, in 2021 there was 1 article and in 2022 there was 1 article. It can be seen that in 2018 there were more roles for articles about Discovery Learning.

Author Keyword-Based Analysis

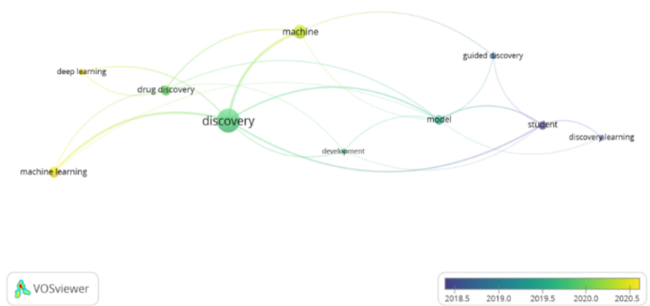
Author keyword analysis was carried out using the VOSviewer application. VosViewer is a freely available computer program for visualizing and exploring bibliometric knowledge maps. The VOS abbreviation in VosViewer is Visualization of Similarities. The algorithm used in this program is almost the same as Multi-Dimensional scaling (MDS). VosViewer-generated clusters are automatically displayed in color on the map. The advantage of VosViewer compared to other analysis applications is that this program uses a text mining function to identify relevant combinations of noun phrases with mapping and an integrated clustering approach to examine data co-citation and co-occurrence networks.

Figure 4 shows the 611 author keywords analyzed with 6 minimum size occurrences. The 10 author keywords produced are very interrelated. The author's 10 keywords are divided into 4 clusters shown in different colors. Cluster 1 in red has 4 items. The words included in this group tend to be general and non-specific words, such as "discovery learning", "guided discovery", "model", and "student", cluster 2 in color in green, there are 3 items, several specific words appear, such as "discovery", "machine", "machine learning", cluster 3 in blue, there are 2 items of words that appear, such as "deep learning", "drug discovery", and cluster 4 in yellow There is a 1-word item that appears, namely "development".

In the visualization, there are nodes (circles) to indicate keywords and edges (networks) to determine the relationship between keywords. The distance of the circles associated with the network shows that the larger the circle, the more variables are studied simultaneously.

Figure 4 shows that keywords that discuss "discovery" get the most results. The keywords whose results appear in cluster 3 (deep learning and drug discovery) and cluster 4 (development) indicate that research discussing Discovery Learning in this area is still limited.

Figure 4. Author Keyword Network Visualization



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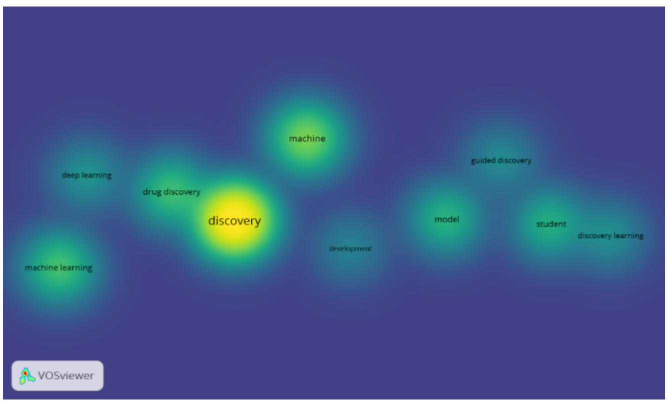

Figure 6. Density Visualization

The cluster density view has items (labels) marked the same as the visible items. Each item point has a color depending on the density of the item. This allows identifying bright spots. This means that there has been a lot of research on discovery learning, but being able to detect very dark spots means that they have not yet been discovered. This shows that research using weak keywords may be explored in the future (Liu et al., 2017).

Discussion

Over the last 10 years, publication of established research results in Scopus-indexed journals on the topic of Discovery Learning only started in 2014. Starting in 2014, research discussing Discovery Learning continues to show changes until 2023. Changes have increased the number of publications. The total number of publications reached 328 articles. This shows that Discovery Learning has been quite popular in educational practice for many years. In these 10 years, the largest increase in the number of publications produced was 34 articles, which occurred from 2022 to 2023. This publication trend pattern is quite popular, so the discussion about Discovery Learning can continue to increase. This happens even though the discovery learning model with e-learning does increase students' involvement and independent learning, their critical thinking skills remain low. The validity and practicality of the discovery learning e-module on environmental change, suggests that the model itself is effective, but further research is needed to understand its impact on critical thinking skills. The potential of the discovery learning model to improve higher-order thinking skills and metacognitive awareness suggests that it may be a valuable tool for improving critical thinking in the context of environmental change (Ayuningsih & Muna, 2023; López et al., 2023).

Research mapping was carried out regarding Discovery Learning. The ten journals presented in Table 2 are Scopus-indexed journals that have contributed the most to publishing articles about Discovery Learning in the last ten years. The journals chosen by researchers for publication also demonstrate the credibility and reputation of the journal, including the credibility of the publisher. Even though there are only journal managers who are out of control in maintaining the quality and quantity, dissatisfaction is indexed by Scopus. This is because the use of Discovery Learning and higher cognitive levels of learning assessment were associated with lower course grades. The impact of Discovery Learning can vary depending on the specific subject and method used.

Of all the articles published, it can be identified which articles have the greatest impact on other research. Citations are one indicator to measure the greatness of a scientist. As it is implied, the extraordinaryness of scientists is measured by the number of their citations. Figure 3 shows that the articles about Discovery Learning with the highest impact came from articles published in 2020 with a total number of citations reaching 1101 from 55 articles. In particular, the article with the highest impact was written by B.R. Goldsmith. An article explaining how One important aspect discussed is the ability of ML to determine active sites in heterogeneous catalysts. With an approach that approaches discovery learning, ML can actively explore the catalyst configuration space to efficiently identify active sites.

Additionally, the integration of ML with quantum mechanics creates a bridge between the classical and quantum worlds, helping to overcome the computational barriers of pure QM. Discussion of supervised and unsupervised learning algorithms is another emphasis. Supervised learning leverages annotated data to make predictions, while unsupervised learning allows the system to explore patterns or relationships without direct guidance. Thus, this article summarizes various ML approaches that can be applied in the context of heterogeneous catalysis, characterizing the essence of discovery learning where systems actively learn from examples and proactively explore (Deiana et al., 2022; Tufail et al., 2023). Judging from the title of Table 3, the Discovery Learning research also explores quite deeply the concept of Discovery Learning in the field of education.

Conclusion

To conclude, 4 problems asked at the beginning can be answered as follows. First, publications about Discovery Learning in Scopus-indexed journals have increased every year for the last ten years. Second, 328 articles from the ten journals that produced the most articles were published. The top-ranked journal published 15 articles, and the tenth-ranked journal published 5 articles. Third, most of the citations occurred in articles published in 2020 with a total of 1101 citations. The most cited article was written by B.R. Goldsmith with 241 citations. Fourth, the author's keywords that are most frequently used in the top three are discovery, machine, and machine learning. Overlay visualization results show that machine learning variables were widely published between 2020 and 2021. In the cluster density view, item points have a color depending on the density of the item allowing identifying bright points. This means that there has been a lot of research on discovery learning, but being able to detect very dark spots means that they have not yet been discovered.

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Author Contributions
Conceptualization, A. S., E. M., Y., and I. M. A., methodology, A. S.; validation, E. M.; formal analysis, Y..; investigation, I. M. A.; resources, A. S. and. E. I; data curation, E. M: writing—original draft preparation, Y. and I. M. A.; writing—review and editing, E. M.: visualization, Y. and I. M. A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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