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Bibliometric Analysis of Adaptive Learning Literature from 2011-2019: Identifying Primary Concepts and Keyword Clusters

Liliia Fadieieva

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Bibliometric Analysis of Adaptive Learning Literature from 2011-2019: Identifying Primary Concepts and Keyword Clusters

Liliia O. Fadieieva[1][0000−0003−4906−2539]

Kryvyi Rih State Pedagogical University,
54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine
liliia.fadieieva@kdpu.edu.ua

Abstract. This paper presents a comprehensive bibliometric analysis of the adaptive learning literature from 2011 to 2019 in the social sciences domain. The study utilizes the Scopus database to identify relevant sources and employs cluster analysis based on keyword co-occurrence to categorize the primary concepts. The research focuses on understanding the key areas and trends within adaptive learning, shedding light on its development and impact over the specified period. The relevance of this analysis lies in the increasing importance of adaptive learning in modern education systems, especially in the context of integrating innovative technologies and addressing the challenges posed by the digital society. As the demand for quality education and skilled teaching staff grows, there is a need to explore and implement more student-centered approaches, such as adaptive learning, to enhance the learning experience and improve educational outcomes. The outputs of this research provide valuable insights into the main themes and areas of interest within the adaptive learning field during the selected timeframe. By identifying primary concepts and keyword clusters, the study offers a comprehensive overview of the key topics, theories, and technologies that have shaped the development of adaptive learning. This analysis can serve as a valuable resource for researchers, educators, and policymakers seeking to understand the current landscape of adaptive learning and explore potential avenues for future research and innovation.

Keywords: Adaptive Learning · Bibliometric Review · Adaptive Systems · Artificial Intelligence · VOSviewer.

1 Introduction

Since Ukraine's policy is aimed at integration into the European Union (EU), we should also take into account the strategic directions for the digitalization of higher education in the EU represented in the Digital Education Action Plan for 2021–2027. It offers a strategy for European education, which includes improved quality and quantity of teaching concerning digital technologies, support for the digitalisation of teaching methods and pedagogies. The Action Plan emphasys to [2]:

– digitally competent and confident teachers and education and training staff [6];
– high-quality learning content, user-friendly tools and secure platforms which respect e-privacy rules and ethical standards [3];
– digital literacy, including tackling disinformation [7];
– good knowledge and understanding of data-intensive technologies, such as artificial intelligence (AI) [8].

Since 2020 (wide spread of the novel coronavirus), and especially since 2022 (Russia's invasion in Ukraine), the Ukrainian teaching staff challenges in performing and managing emergency distance education [5]. This rise a lot of issues both technical and organizing which made a drastic changes in the Ukrainian educators' digital competence. For the first time, the educational community has been self-organized to prevent a disruption of education on the all levels, from pre-school to tertiary. There is a growing interest in more flexible, innovative and sustained models of professional development, in particular where educators learn from their peers.

In addition, the emergence of new technologies such as AI, virtual or augmented reality and social robotics, challenge educators and requires them to take a more active role in the design and implementation of these tools to ensure their use is effective, desirable and inclusive [1].

Overall, there is a need to develop and test new pedagogies and techniques, also by investigating how emerging technologies can be smoothly integrated in existing teaching and learning practices. One of the prominent application of AI in education is a technology supported adaptive learning.

2 Method

To systematize available scientific knowledge, a bibliometric analysis was conducted using the VOSviewer [4]. In order to carry out the analysis, a selection of sources from the scientometric database Scopus was made upon request:

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TITLE("adaptive learning") AND (LIMIT-TO(SUBJAREA, "SOCI"))
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According to the request, the term "adaptive learning" appeared in the titles of articles, chapters, or books belonging to the subject area "social sciences".

3 Results and Discussion

As a result, 344 documents were received, and the distribution of works by year is presented in figure 1.

Cluster analysis by keyword co-occurrence was conducted: from 1836, keywords were selected, that appeared at least 10 times (table 1).

The results of the cluster analysis are presented in figure 2.

According to table 1 and figure 2, keywords were divided into five clusters. Let's analyze them in more detail.

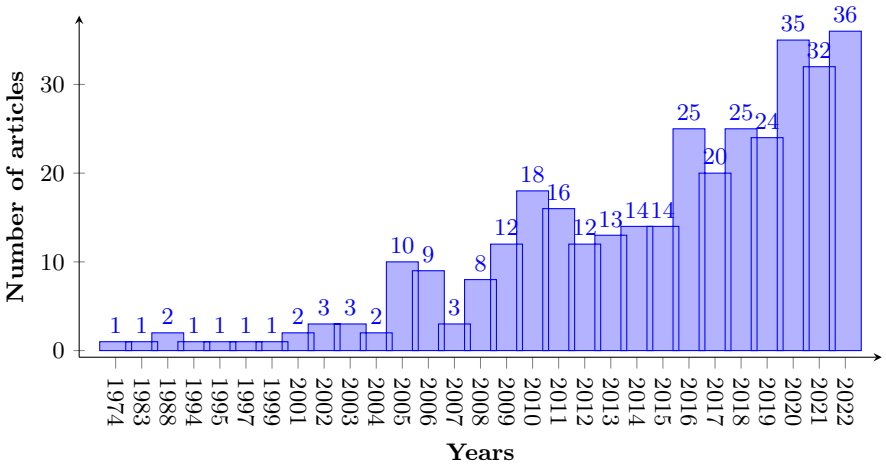

Fig. 1. Distribution by articles by years.

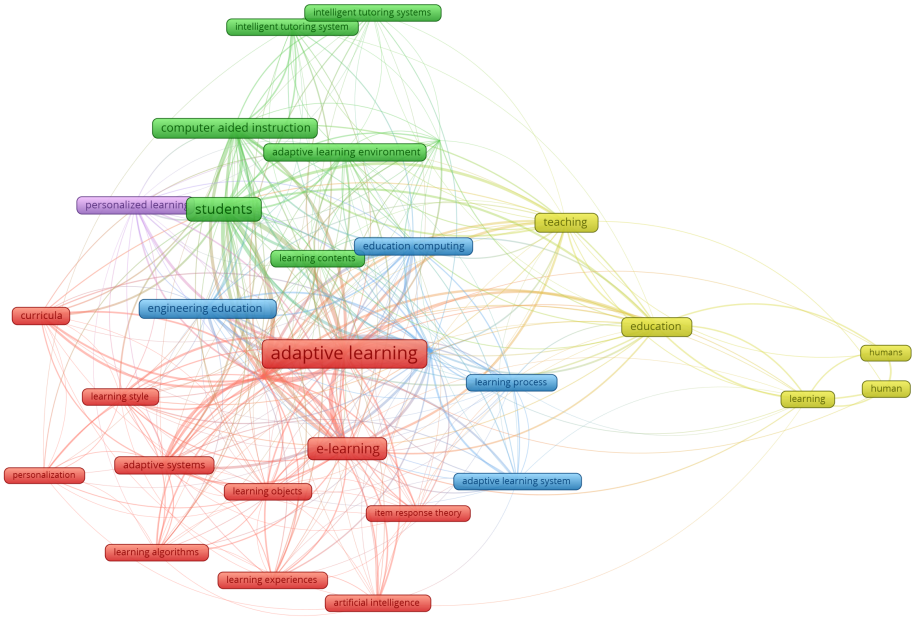

Fig. 2. Network visualization.

The first cluster includes 12 keywords (figure 3), 5 of which are primarily related to the theory of adaptive learning: *adaptive learning*, *adaptive systems*, *curricula*, *learning style*, *learning experiences*, *learning algorithms*, *personalization*. Other concepts are related to adaptive testing (*item response theory*), which

Table 1. Distribution of keywords by clusters.

Keyword	Cluster	$\text{Weight}_{\text{Links}}$	$\text{Weight}_{\text{Total link strength}}$	$\text{Weight}_{\text{Occurrences}}$	$\text{Score}_{\text{Avg. pub. year}}$	$\text{Score}_{\text{Avg. citations}}$	$\text{Score}_{\text{Avg. norm. citations}}$
adaptive learning	1	29	425	158	2016.0443	10.6076	0.966
learning systems	1	27	445	118	2014.6356	10.6949	0.8159
e-learning	1	27	280	70	2015.4571	6.6857	0.7592
adaptive systems	1	25	126	28	2013.6429	28.3929	1.1589
learning objects	1	22	46	12	2012	24.8333	1.6496
learning style	1	21	72	17	2013.4706	32.4118	1.5342
learning algorithms	1	20	53	13	2015.4615	34	1.6297
learning experiences	1	19	56	11	2015.4545	9.2727	1.1661
artificial intelligence	1	18	41	14	2016.6429	7.8571	0.8118
item response theory	1	18	33	10	2017.3	17.1	1.8503
curricula	1	17	78	21	2014.7143	7.9048	0.8894
personalization	1	14	27	10	2013.9	70.8	3.1478
students	2	26	338	75	2015.68	11.72	1.0332
computer aided instruction	2	25	209	40	2014.975	13.975	1.0588
adaptive learning environment	2	23	82	19	2014.4211	14.5263	1.4182
learning contents	2	20	49	11	2013.6364	11.6364	0.9208
learning performance	2	19	48	11	2014.1818	11.3636	0.8037
intelligent tutoring system	2	17	49	11	2014.5455	22.0909	1.4888
intelligent tutoring systems	2	15	34	12	2017.9167	15.6667	1.9702
adaptive learning systems	3	27	269	66	2015.1667	7.9697	0.8392
education computing	3	25	135	25	2015.96	4	0.5437
engineering education	3	23	121	29	2013.7931	6.8966	0.7189
learning process	3	20	48	12	2016.5833	4	0.5026
adaptive learning system	3	19	58	15	2016.4667	9.8667	0.8269
education	4	25	144	35	2011.8286	11.8286	0.7189
teaching	4	25	133	29	2015.7931	8.1379	0.6896
learning	4	12	38	17	2015.0588	5.9412	0.5421
human	4	5	29	11	2013	12.0909	0.8125
humans	4	5	27	10	2015.5	10.3	0.8126
personalized learning	5	20	79	21	2017.7619	14.5714	1.3967

is implemented in *e-learning* systems – a type of *learning system* that operate with *learning objects* and can be automated by means of *artificial intelligence*.

The second cluster contains 7 keywords (figure 4) related to the practice of *computer aided instruction* of *students* (in particular, assessment of *learning per-*

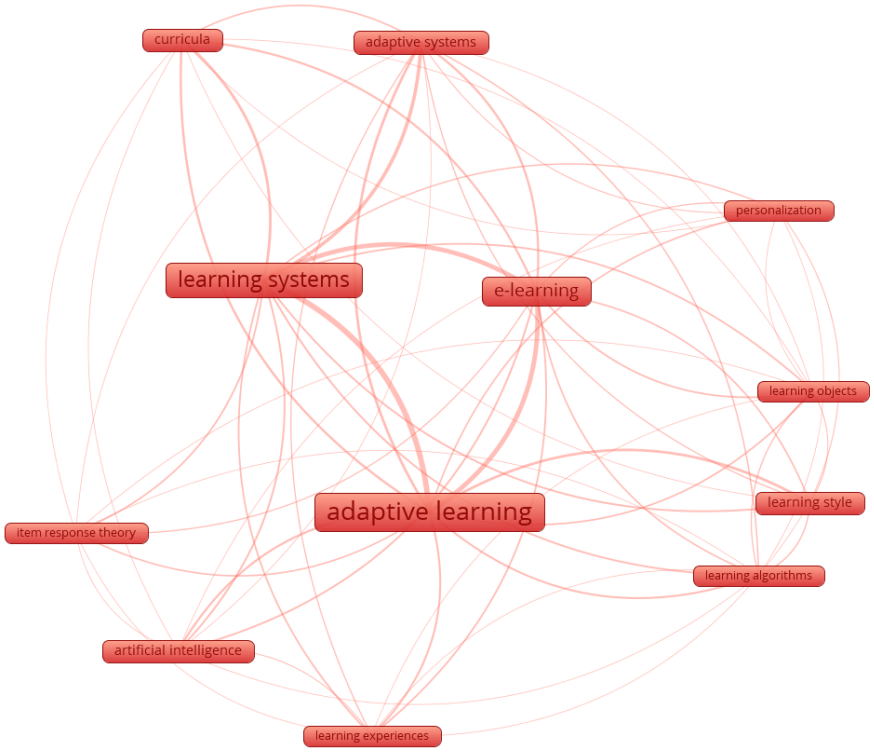

Fig. 3. A cluster of general concepts of adaptive learning in e-learning systems.

formance, and evaluation of *learning contents*) at *adaptive learning environment* (in particular, *intelligent tutoring systems*).

The third cluster contains 5 keywords (figure 5) that describe the implementation of *learning process* within *engineering education* by means of *education computing*, e.g. *adaptive learning systems*.

The fourth cluster also includes 5 keywords (figure 6) that describe the didactic fundamentals: *human(s)*, *education*, *teaching*, and *learning*.

The smallest cluster consists of only 1 keyword (figure 5) – *personalized learning*.

Another important criterion for source analysis is density. First, was analyzing the item's density (figure 7). From this visualization, the keywords "adaptive learning" ($\text{Weigth}_{\text{Total link strength}} = 425$), "learning system" ($\text{Weigth}_{\text{Total link strength}} = 445$), "students" ($\text{Weigth}_{\text{Total link strength}} = 338$), and "e-learning" ($\text{Weigth}_{\text{Total link strength}} = 280$) have the highest density. These items are the most interconnected (maximum value of total link strength).

In order to determine primary concepts (earliest keywords by time scale), let's show overlay data visualization by years. As is shown in figure 9, there are no fundamentally new concepts, their emergence, and spread have occurred at

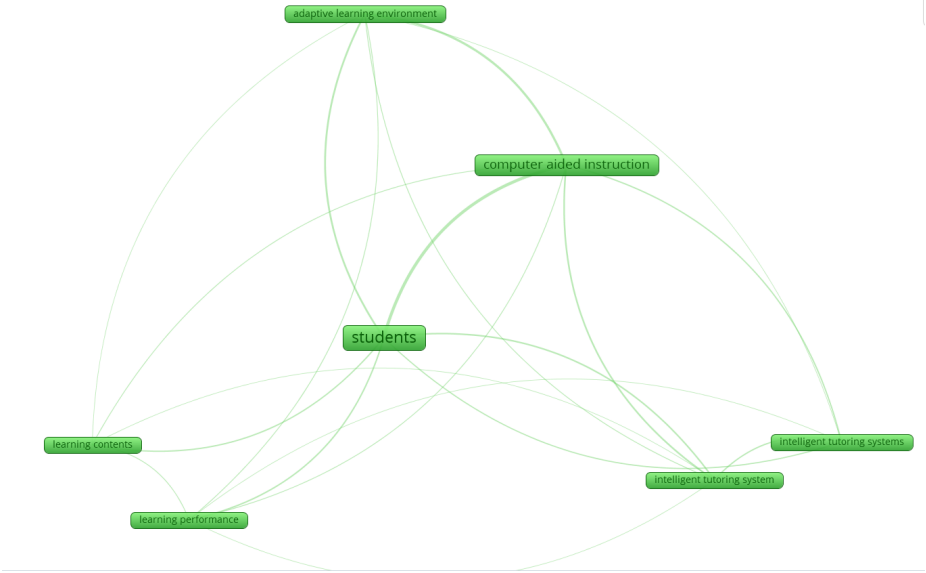

Fig. 4. A cluster of educational technology.

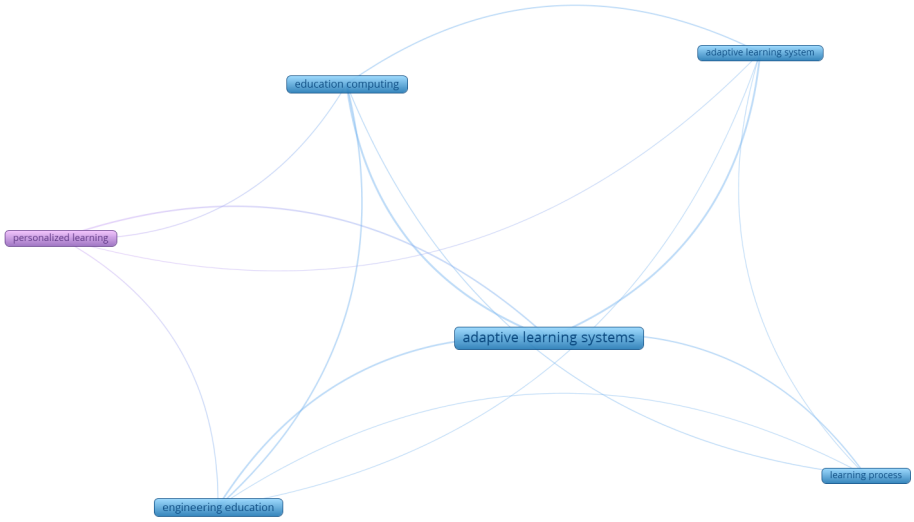

Fig. 5. A cluster of adaptive learning systems and education computing.

least since 2020. There are also no concepts that were widespread before 2000. This visualization gives us grounds for limiting the analysis years.

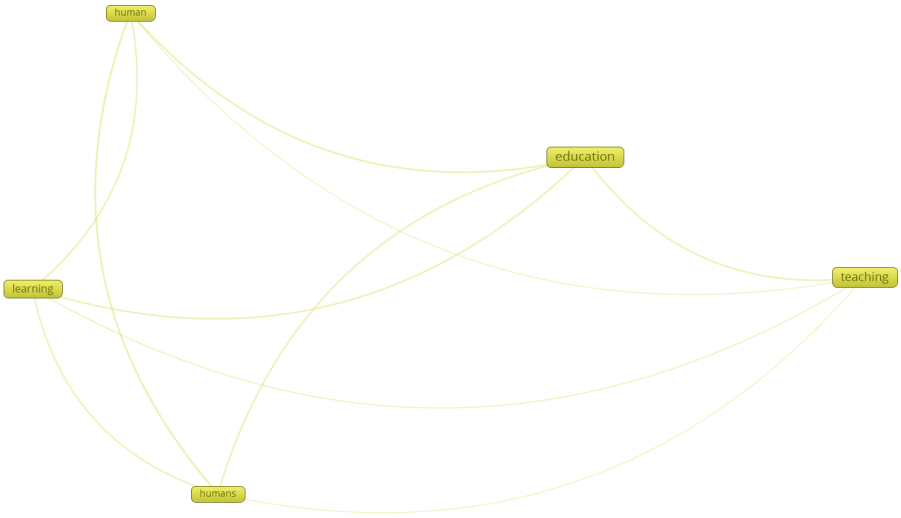

Fig. 6. A cluster of learning and education research.

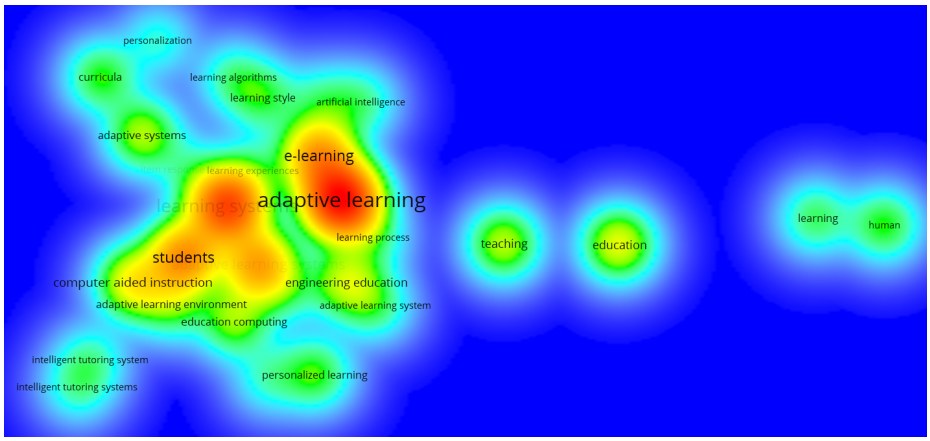

Fig. 7. Item density visualization.

So, let's analyze these concepts from 2000 to 2020 (figure 10). Within these limits, we can see that such concepts as *"human(s)"*, *"education"*, and *"learning objects"* begin to stand out as those that were formed earlier. At the same time, such concepts as *"personalized learning"* and *"intelligent tutoring systems"* are distinguished as those highlighted later. And since most of the concepts were disseminated after 2000, to see their distribution more accurately, we will raise the lower limit from 2000 to 2010 (figure 11).

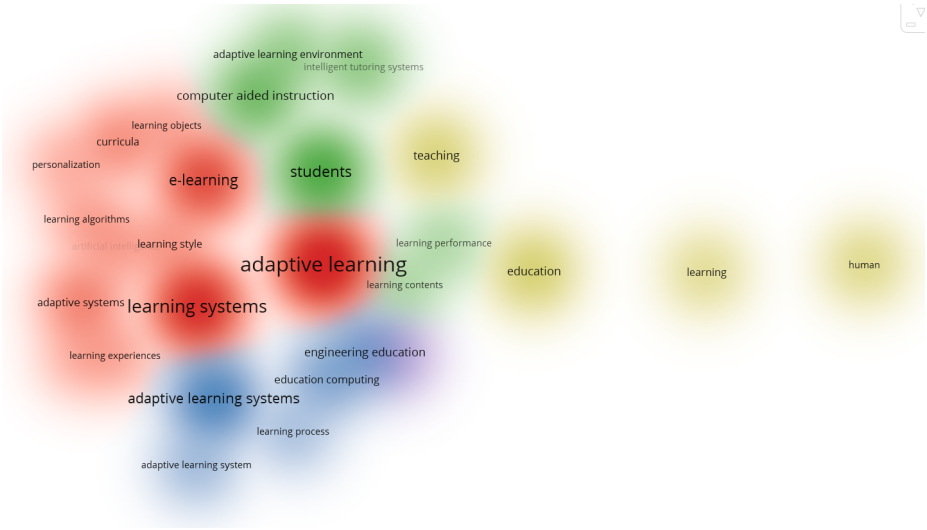

Fig. 8. Cluster density visualization.

When comparing figure 11 with figure 10, we observe that most of the concepts have changed color, but it is still unclear which concepts were discussed by researchers in the different years.

So, let's try to change both the upper and lower limits for 1 year, i.e. from 2011 to 2019 (figure 12). Now we can observe a more transparent distribution of concepts by time scale. From this figure, we can see that adaptive learning and artificial intelligence became disseminated later than those related to the use of ICT in education.

4 Limitations

The use of only the Scopus database and the social sciences section of this database instead of the entire range are the key restrictions on the research. Additionally, sources like tech reports and Ph.D. theses that are not indexed by Scopus can be useful for this research. There are some restrictions with the VOSViewer tool: a clustering algorithm was applied with the default settings, and the low limit for keyword occurrence was set at 10. The number of clusters can be decreased or increased depending on the clustering settings. Additionally, the third cluster can be combined with the fifth one because the fifth cluster only has one keyword (personalized learning).

5 Conclusions

Several important conclusions resulted from the bibliometric review. To begin, the research focused on publications from 2011 to 2019, a period that showed a

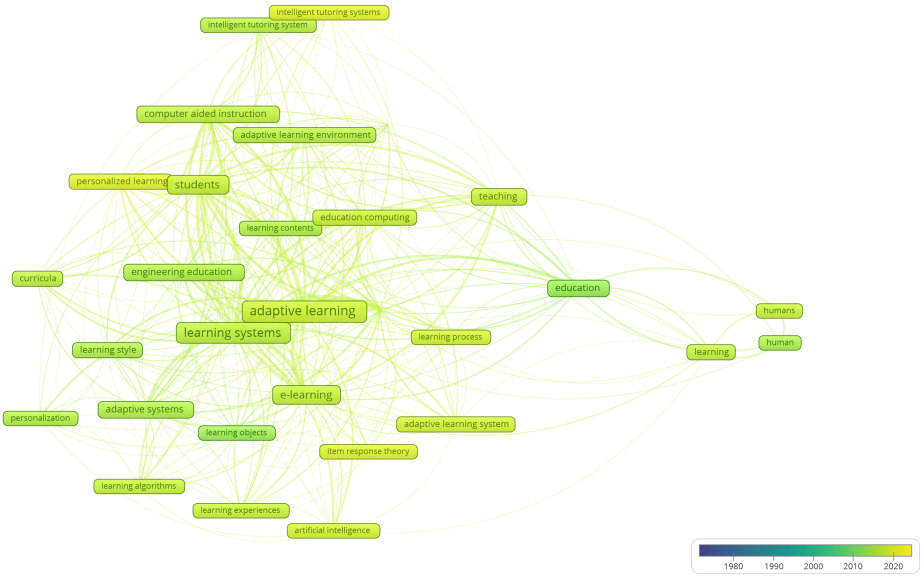

Fig. 9. Extension of terms from 1974 to 2022.

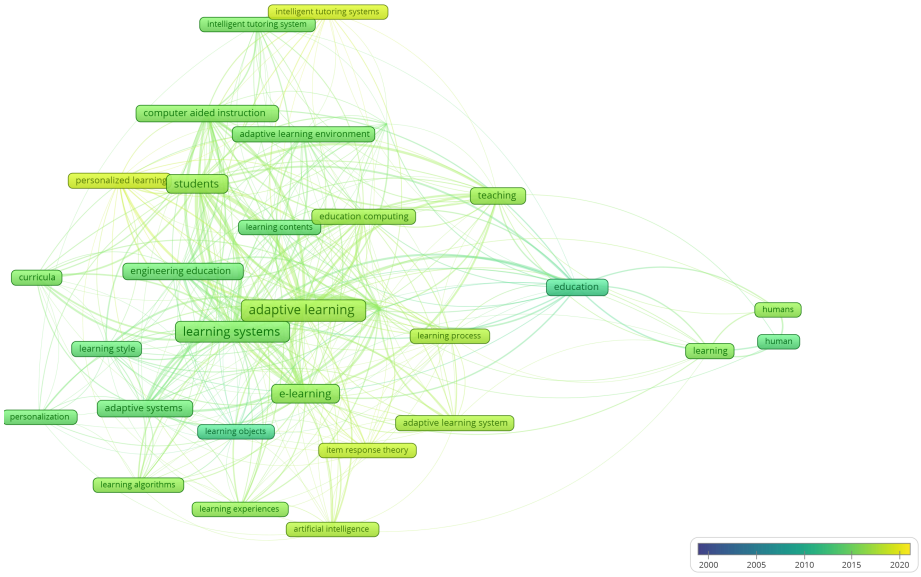

Fig. 10. Extension of terms from 2000 to 2020.

large increase in interest in adaptive learning. Using cluster analysis, the study successfully identified the research problem domain.

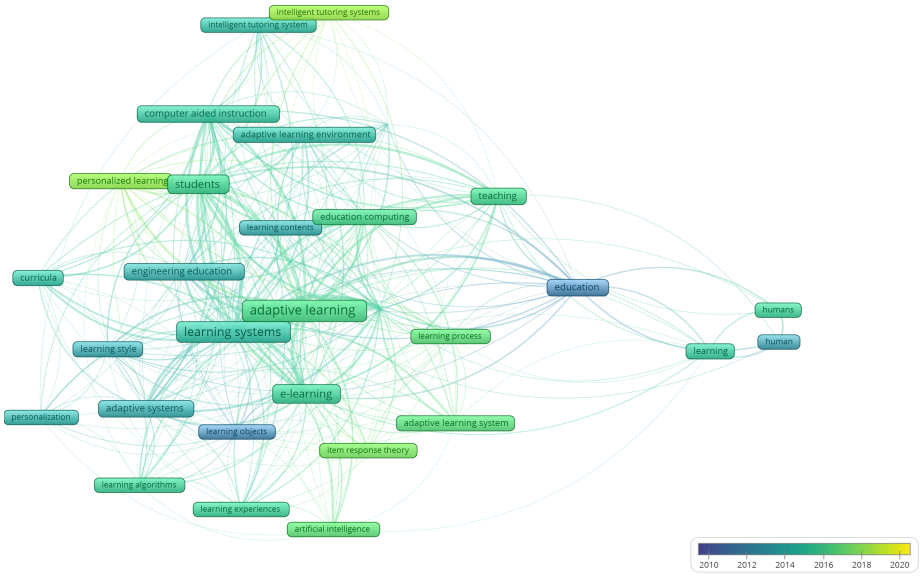

Fig. 11. Extension of terms from 2010 to 2020.

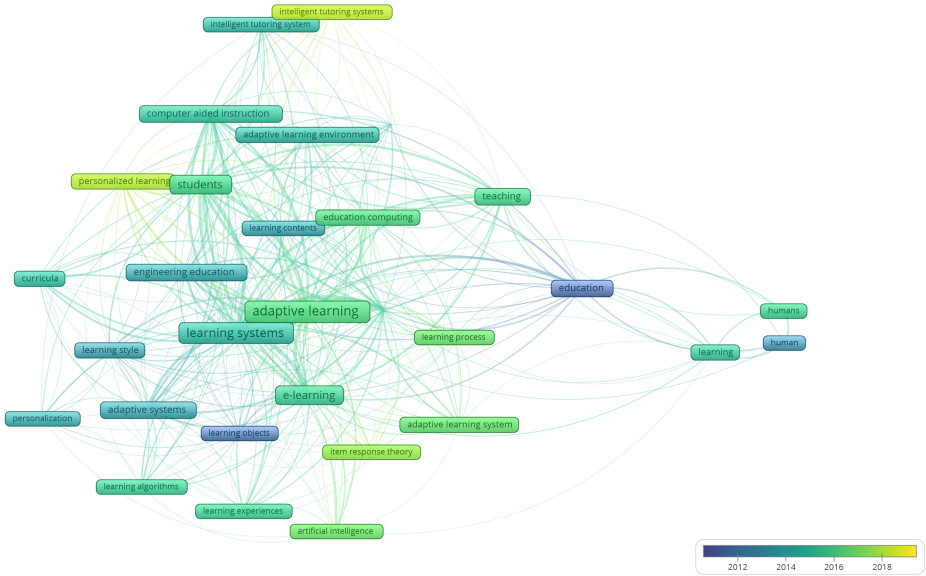

Fig. 12. Extension of terms from 2011 to 2019.

Adaptive learning, learning systems, e-learning, adaptive systems, learning objects, learning style, learning algorithms, students, computer-aided instruc-

tion, adaptive learning environment, learning contents, adaptive learning systems, education computing, engineering education, learning process, education, teaching, and personalized learning were also established as key concepts central to the subject.

6 Future Work

The results of the bibliometric analysis have provided valuable insights into the current state and emerging trends in adaptive learning literature. Building on this analysis, several areas of future research can be explored to advance our understanding of adaptive learning and its applications in education:

1. *Systematic Review*: Conduct a comprehensive systematic review of the identified clusters to delve deeper into the current state of research in adaptive learning. This review can focus on specific themes such as the theory of adaptive learning, learner's models, the effectiveness of adaptive learning systems, and the integration of AI in adaptive learning platforms.
2. *AI-driven Adaptive Learning*: Investigate the role of artificial intelligence in the development and improvement of adaptive learning systems. Explore the use of advanced AI algorithms and approaches to enhance the adaptivity and personalization of learning experiences.
3. *Evaluation and Effectiveness*: Examine the implementation and effectiveness of adaptive learning systems in educational settings. Conduct empirical studies to assess the impact of adaptive learning on student performance, engagement, and satisfaction.
4. *Adaptive Learning Environments*: Explore the design and development of adaptive learning environments that cater to individual learners' needs and preferences. Investigate how adaptive systems can be integrated into existing educational platforms to create personalized learning experiences.
5. *Gamification and Adaptive Learning*: Investigate the potential of gamification techniques in adaptive learning systems. Explore how gamified elements can enhance student motivation, engagement, and learning outcomes.
6. *Learning Styles and Personalization*: Study the role of learning styles in adaptive e-learning hypermedia systems. Investigate how learning styles can be effectively integrated into adaptive learning platforms to cater to diverse learner preferences.
7. *Adaptive Learning in Mathematics Education*: Focus on the application of adaptive learning and intelligent tutoring systems in mathematics education. Explore how adaptive approaches can enhance student learning and problem-solving skills in this domain.
8. *Analytics and Adaptive Learning*: Explore the use of learning analytics in adaptive learning systems. Investigate how data-driven insights can be utilized to personalize learning pathways and support educators in making informed decisions.

9. *Application in Different Educational Settings*: Investigate the implementation of adaptive learning and analytics in various educational settings, including K-12 schools, higher education institutions, corporate training, and online learning platforms.
10. *Ethical and Privacy Considerations*: Examine the ethical and privacy implications of using adaptive learning systems, especially when leveraging AI and data-driven approaches. Address concerns related to data security, bias, and transparency.

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