Proceedings of the 6th International Conference on Computing and Data Science
DOI: 10.54254/2755-2721/90/20241720

A review of research on the utilization of deep learning in adaptive learning 2014-2024

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Abstract. Deep learning is a highly popular and rapidly advancing technology in today's world. Adaptive Learning based on learner's individual needs shed lights in education. The combination of them may be the pivotal point in the future. This is a review mainly concerns the application of deep learning(DL) in adaptive learning(AL). The search is carried on Web of Science and Scopus. The author proceeds the research by asking several questions regarding the category of deep learning application in Adaptive Learning, the strength and weakness of those publications and the gap for future scientific research concerning deep learning in AL. This study finds some patterns in research category, figure out the most of the current researches resides in KT. One of the key advantages of deep learning is its capacity to closely mimic the structure and operational mechanisms of the brain. While it has weakness in computation cost, hardness in interpretation and data collection and so forth. This study points out the gap of research may lie in how to use deep learning to find the representation and leverage LLM in adaptive learning.

Keywords: adaptive learning, personalized learning, deep learning, DL, AI, machine learning, DKT.

1. Introduction

1.1. Adaptive learning

The world operates in a non-linear fashion; hence, learning should be designed to effectively align with this complexity to enhance adaptability. Therefore, the learning process itself must also embrace a non-linear structure. Engaging in a linear pattern of learning can result in advanced learners redundantly revisiting knowledge they have already mastered, leading to inefficiencies in time and effort. Furthermore, the absence of interactive elements in linear learning environments may hinder the provision of prompt feedback and assistance. Additionally, segmented or decomposed learning content still lacks way to transition to subsequent stages or topics further exacerbates this issue.

Educational Artificial Intelligence is a field combine with AI and education. It has two goals: one is to promote the implementation of AI tools in education with high efficiency, high flexibility and individuation. Another is to use precise calculating and explicit form to express some ambiguous knowledge in Education, Psychology and Sociology. Artificial Intelligence (AI) has emerged as a pivotal tool in unraveling the enigmas of cognitive learning within the human brain.

The study introduces the concept of adaptive learning, which is a research branch of e-learning, Adaptive learning refers to a personalized educational approach that tailors learning experiences based

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on the individual needs, preferences, and abilities of learners. It utilizes various technologies and data analytics to create customized learning paths, thereby enhancing the educational experience. The primary feature of adaptive learning is the continuous assessment and adaptation of learning materials, which allows for the recommendation of personalized learning items such as lectures and exercises. This method helps educators provide more effective support to large groups of learners, particularly in massive open online courses (MOOCs)

However, relying solely on adaptive learning to enable scholars to achieve self-driven learning, improve meta-cognitive levels, and comprehensively enhance learning capabilities may be impractical.

1.2. Deep learning

Deep learning is a specialized branch of machine learning that utilizes artificial neural networks to model and solve complex problems. It is heavily inspired by the structure and function of the human brain, particularly the inter-connectedness of neurons. This advanced approach allows deep learning algorithms to learn from vast amounts of data, making it effective for tasks such as image recognition, natural language processing, and more.

1.3. Deep learning in adaptive learning

The utilizing of deep learning in adaptive learning enables the provision of personalized educational pathways and content recommendations. Leveraging deep learning techniques, the system can automatically adjust learning materials and progression based on students' learning behaviors, abilities, and requirements. Adaptive learning, driven by students' feedback and performance, tailors the learning path accordingly, while deep learning aids in a better comprehension of students' learning states and needs, facilitating the delivery of more personalized and effective learning experiences. This amalgamation serves to enhance learning efficiency and outcomes.

2. Literature Review

2.1. Different type/strategy of adaptive learning

When it comes to adaptive learning, there are three types need to be specified here:

1. Adaptive content: adjusts to individual learner needs, offering personalized

educational material. Tailored to user proficiency and preferences, it enhances engagement and learning outcomes by delivering relevant and targeted information, fostering a dynamic and adaptive learning experience.

2. Adaptive assessment: tailors evaluation methods to individual learner abilities and knowledge levels. By dynamically adjusting question difficulty and content based on responses, it provides accurate and detailed insights into each learner's strengths and weaknesses, enhancing the assessment process's effectiveness and precision.

3. adaptive sequencing: organizes learning materials based on learner progress and performance. It dynamically adjusts the order and complexity of content delivery

to optimize comprehension and retention, ensuring a personalized and effective learning path for each individual.

The research conducted by Delgado encompasses a wide range of perspectives in the field[1]. In addition, several other studies have introduced alternative viewpoints, such as the examination of AI-supported personalized teaching strategies and the exploration of Adaptive Learning Path Construction[2,3]. These diverse lines of inquiry collectively contribute to a more nuanced understanding of the subject, highlighting the multifaceted nature of the research landscape.

2.2. Building block

The present adaptive learning systems or platforms can be constructed using various frameworks, each comprising distinct components. Zhao & Wang center their analysis on a framework consisting of three primary modules: the knowledge network model, the cognitive level model, and the adaptive

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recommendation model[4]. This particular framework serves as the foundation for various adaptive learning systems.

In addition, other scholarly articles and books discuss an alternative, widely recognized framework that encompasses several essential adaptive learning components. These include the learner model, also referred to as the user model, which structures the student's characteristics, the knowledge domain model, the instruction model, the adaptive model, and the user interface[5,6,7]. Collectively, these elements form a robust structure that supports the design and implementation of effective adaptive learning systems. The user model is currently considered as the key part of it, it could base on learning style (LS), learning objectives, cognitive level, emotion status, and learning environment.

This part has attracted a significant number of scholars to conduct research.

2.3. Data and algorithm

From the perspective of adaptive learning technologies, the core algorithms employed in adaptive learning encompass the K-means clustering algorithm, ant colony algorithm, Memetic algorithm, Bayesian algorithm, collaborative filtering algorithm, and hybrid algorithms [8,9,10,11,12,13]. Among prevalent recommendation models are collaborative filtering recommendation, knowledge-based recommendation, association rule recommendation and hybrid recommendation. Collaborative filtering, the earliest and most widely applied pattern in recommendation systems, primarily determines suitable knowledge for target users by assessing the similarity between the target user and a group of neighboring users.

Considering learning styles, there are algorithms based on ant colony optimization (ACS), association rule mining (IDEAL), Honey and Mumford's learning style model (INSPIRE), Felder-Silverman's learning style model, Tangow, MANIC, MASPLANG and LSAS, among others.

From a cognitive level perspective, there exist algorithms based on genetic algorithms (PELS) and association rule algorithms (ELM-ART).

3. Methodology

3.1. Protocol

This research aims to comprehensively document and trace the research regarding applying deep learning in adaptive learning; publications were collected in two large bibliographic databases: Web of Science (WOS) and Scopus; since they are esteemed for their large repository of scholarly publications. Additionally, known for their exceptional quality and academic rigor.

The time scope of the publications to be concerned is published from 2014 onwards; as result of getting some latest research results; and this research is carried on around July and August in 2024, so the end time for the collections is set to August 15,2024.

The investigation is carried on with topic (title, abstract and keywords) as search field and the collection of publications is exported to EndNote software in order to remove duplication, the author does some further inspection to make sure the article is on-topic based on some criteria.

Afterwards the author does some classification inside the collection.

The author makes the search phrase:("adaptive* *learning") AND ("deep learning" OR"DL" OR "deep neural* network" OR "deep network") AND "education". This study does the search of publications separately in WOS and Scopus

The search result is 75 articles from Scopus and 21 from WOS; combine them comes out the collection of 96 articles, then the author removes duplicated work, leaves 76 articles remaining, then the author removes the ones off topic, off topic means the article is either not involve adaptive learning or not related to deep learning or both. After one-by-one coding there are 39 articles left. Please see the fig 1

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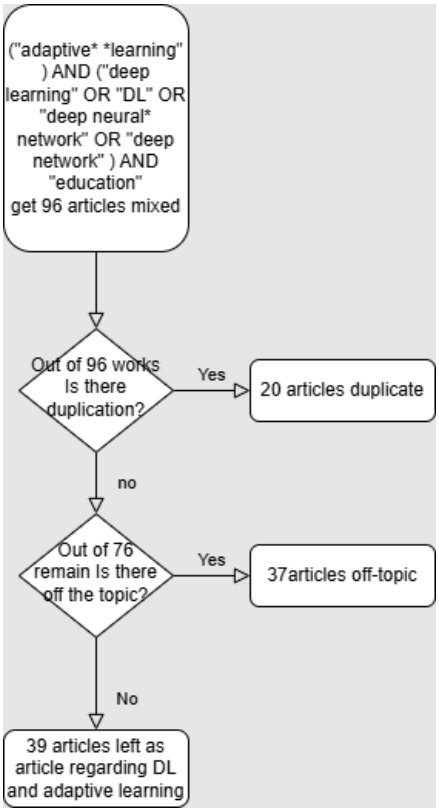

Figure 1. document process

3.2. Research Questions

RQ1: How should publications be categorized according to a taxonomy.

RQ2: What are the strengths, limitation and main concerns of applying deep learning in adaptive learning.

RQ3: What are the key research gaps should be investigated according to the existing works?

4. Result

The study shows the result of RQ1 in table 1 attached, the most of articles (7) are doing research on deep learning with knowledge tracing, that is to get the learner's master level of the knowledge, which is indeed critical. The deep learning with RNN is also popular, which is related to the sequence understanding or sequence generating. There are three works investigate the use of deep learning in emotion recognition. Moreover,some scientists examine the application of deep learning with gaming, since there are two attempts to investigate game strategy and mechanism in adaptive learning. Surprisingly,It may be expected there are many works regarding the deep learning with robot in adaptive learning but there is not substantial quantity of them, actually only two involved. The study on deep learning in EEG is a great attempt since it directly examines "read human mind" as the way to implement adaptive learning strategy. The deep learning in representation and deep learning in GPT has two and one publications collected, respectively.

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Table 1. research result

research topic	count	representative work
deep learning with KT	7	Evaluating Deep Sequential Knowledge Tracing Models for Predicting Student Performance[14]
deep learning with RNN	3	Are We There Yet? Evaluating the Effectiveness of a Recurrent Neural Network-Based Stopping Algorithm for an Adaptive Assessment[15]
deep learning with gaming	2	Modeling Learners to Early Predict Their Performance in Educational Computer Games[16]
deep learning in robot	2	Robust Model for Rural Education Using Deep Learning and Robotics[17]
deep learning in emotion recognition	3	An optimized deep convolutional neural network for adaptive learning using feature fusion in multimodal data[18]
deep learning in EEG	1	Prediction of Cognitive Load from Electroencephalography Signals Using Long Short-Term Memory Network[19]
deep learning in representation	2	A case study on the use of semantic web technologies for learner guidance[20]
deep learning in GPT	1	AI Tutor Enhanced with Prompt Engineering and Deep Knowledge Tracing[21]

AS for the RQ2, deep learning already plays a key role in knowledge tracing. It has the characteristic of mimic human brain's mechanism which make it could simulate our brain's functionality and decipher the complex activity of our thinking or reasoning process. It also has the strength to get better precision when doing some predictions which are conventionally handled by basic machine learning or rule-based algorithm. Use deep learning in robot to get some feedback and interaction with computer is also a very fascinating part of the research. The limitation lies in deep learning is it asking for great computing efforts, which may lead to large amount of computing resource cost. Another problem is deep learning is hard in interpreting how it works, which sometimes called "black box", unlike human build model like Bayesian knowledge tracing, which can always be explicitly elucidated that how it provide us the specified answer. The last but not least limitation is that deep learning need a lot of data which is generated continuously, not all adapt learning platform can produce such great amount of data.

As for the RQ3, one essential role of deep learning is to unravel the representation of something, as the cognitive tool of understanding unstructured information, especially for some relationship or concept hardly perceived by human being. More scientists are expected to do some exploration on employing deep learning in representation (only two in list). Which may be a research gap the author looks forward to bridge. Lastly, this study wants to explore GPT, the large language model (LLM) already has application everywhere, however, seems in adaptive learning, how to use its power is still some field we need to explore.

5. Discuss

In the search the author didn't use CNN or RNN as key words (as alternative to deep learning), which may bring in more result. But that related to computer vision and nature language process, and the development of those may be more general than just in adaptive learning.

As for the limitation of lack of tremendous data for training deep learning model, one can think of the wearable device. The use of wearable devices in adaptive learning is promising. These devices have the potential to monitor students' real-time physiological states, attention levels, and learning progress, providing more precise data support for personalized learning. By integrating data from wearable devices with deep learning algorithms, it is possible to adjust learning content and pacing based on students' bodily feedback, offering a more effective learning experience. This integration is poised to bring about a more intelligent and personalized learning approach in the education sector, enhancing learning outcomes and teaching quality.

Finally, the author intends to address the importance of combining research in psychology, machine learning and education science. Numerous theories and discoveries abound in the realms of psychology and educational science. Among these, the Information Processing Theory dissects human thought processes akin to a computer; Cognitive Semiotics delves into the conveyance of meaning through symbols; and Cognitive Load Theory probes the mechanisms by which information is stored in our memory. Scientists could bring them together into adaptive learning, along with deep learning, to get better result of future education.

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