# Progress, Challenges and Countermeasures of Adaptive Learning: A Systematic Review

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**ABSTRACT:** With the deep application of artificial intelligence and big data in education, adaptive learning has become a new research hotspot in online education. Based on the systematic review of the connotation and research progress of adaptive learning, a new definition of adaptive learning is given. By literature analysis, this paper points out the challenges faced by adaptive learning research, such as the lack of cognition of brain and technology, the bottleneck of the model of emotion domain, the separation of education and technology, the security of data management and the risk of privacy leakage. These challenges can be summarized into two aspects: one is mechanical issues, the other is safety issues. Different from traditional research perspectives, the paper opens a new research window, and puts forward countermeasures from the perspectives of cognitive principles, zone of proximal development theory in technology, breakthrough in the emotional domain model, learning data management and privacy security. In view of the centralization of learning data management nowadays, the concept of code chain and the decentralized management mode based on code chain are proposed. Different from the traditional adaptive learning recommendation technology, a new adaptive learning pulling model is proposed.

**Keywords:** Adaptive learning, Learning recommendation, Learning pulling, Code chain technology, Data security

## 1. Introduction

In recent years, “learner-centered” - based individualized education and learning has become a new trend in the development of education in the world. Education departments of lots of countries have formulated action plans in response. Singapore has implemented the plan that each student has a learning terminal to support students’ personalized learning (Lan, 2015). The “Vision 2020” published by the UK government sets out the relevant issues that need to be addressed in personalized learning (Li, 2008). In South Korea, the Ministry of Education, Science and Technology issued the implementation plan of promoting intelligent education strategy, to comprehensively carry out intelligent education and implement personalized teaching and learning (Piao, 2012). The U.S. Department of Education released the report “Promoting Teaching and Learning through Educational Data Mining and Learning Analysis” to really realize personalized learning with the help of big data (Xu, Wang, Liu, & Zhang, 2013). Ten-year Development Plan for Educational Informatization in China (2011-2020) points out that “an information-based environment should be built to provide personalized learning services for each student” (The Ministry of Education of China, 2012). However, most current online education platforms only share learning resources, including teachers, courses and other hardwares and softwares, to learners, but fail to provide targeted learning support at a specific time. In addition, for a large number of learners, it is difficult for teachers to achieve effective interaction with learners. Therefore, learners’ individual needs cannot be really met.

However, the personalization of learning can be achieved using various methods that have been made available by the rapid development of Information Communication Technology (ICT) (Dawson, Heathcote, & Poole, 2010). Adaptive or personalized learning has become possible by implementing intelligent learning systems, integrating learners’ preferences, analyzing individual learning data, and so on (Xie, Chu, Hwang, & Wang, 2019). Adaptive learning can achieve the requirements of personalized learning. According to different learners’ learning styles, learning levels and cognitive abilities, it can provide targeted services, such as learning content and path recommendation and intelligent tutoring, and provide personalized learning support for learners.

Adaptive learning is an emerging development that has been mentioned in The NMC Horizon Report (Higher Education Edition) since 2004 by The New Media Consortium. It is recognized as a major advance in higher education for two consecutive years in 2015 and 2016. The World Economic Forum (2020) released a report entitled “The School of the Future: Defining a New Education Model for the Fourth Industrial Revolution,” which proposed a global framework of “Education 4.0,” namely eight key characteristics of learning content and

experience. The seventh and eighth key features especially emphasize the importance of personalized learning and autonomous learning. This fully indicates that adaptive learning has become an important proposition and a new teaching paradigm in the development of education in lots of countries (Xie, Chu, Hwang, & Wang, 2019), and the research on adaptive learning has become a major topic in the field of education science. Xie et al. (2019) points out that technology-enabled adaptive or personalized learning has been a popular and important research direction in the field of educational technology.

Theoretically, with the continuous emergence of new technologies such as human-computer interaction in online education, sentiment analysis, big data and intelligent robots, and the deep integration of artificial intelligence technology and education, adaptive learning enables students to break through the limitations of regions and time. According to their own needs, learners can independently control the learning progress, improve the learning efficiency, and can achieve open, sharing and ideal learning state. But in the reality of teaching and learning, it does not produce the expected effects. On the one hand, the adaptive learning system is still immature and faces many difficulties and challenges, such as the separation between education and technology, the transmission bottleneck in the emotional field, the security of learning data management and the disclosure of learner privacy. On the other hand, the homogenization of adaptive learning is serious (Chen, 2003). Different from the previous research perspective, first of all, we define the concept of adaptive learning from a new perspective. Then, through literature analysis, we systematically elaborate the research progress, and try to find out the specific problems in the study of adaptive learning. Next, through deep analysis, the main causes of these problems are found out. Finally, innovative theory and coping strategies are put forward. To sum up, the research questions are:

- What are the problems and challenges faced by adaptive learning research at present?
- What are the causes of the problems?
- What are our strategies in the face of challenges?

## 2. Literature review

The essence of adaptive learning is scaleable personalized learning, which is closely related to autonomous learning, personalized learning and individualized learning, and its concept is easily confused. At the same time, with the development of information technology, its research connotation has also changed a lot. According to the technical level, adaptive learning is divided into three kinds: artificial learning, computer programming and artificial intelligence. Modern adaptive learning, as a product of artificial intelligence and "Internet +" education era, has been regarded as a new educational technology innovation (iResearch, 2018). Therefore, it is necessary to reorganize and define again from four categories: concept, system, model and technology.

### 2.1. Concepts of adaptive learning

There is no unified view on the concept of adaptive learning in academic circles. It is generally accepted that adaptive learning refers to the learning mode that provides corresponding learning environment, examples or fields for learning, and through the discovery and summary of learners themselves in learning, finally forms theories and can solve problems independently. Peter Brusilovsky (1996) from the University of Pittsburgh proposed that adaptive learning is based on individual differences in learners' knowledge background, learning attitude, learning style, learning ability and other aspects. Zhu (1997) put forward the "conditional construction-optimization theory" of adaptive learning, and systematically elaborated the information processing process in which people acquire knowledge and skills through example learning. From the perspective of "teaching," Zhao, Xu, and Long (2015) believed that adaptive learning meant that teachers used adaptive learning systems as teaching aids to collect and analyze data, prepare lessons, understand the learning state, evaluate, and timely adjust the teaching content to meet the changing learning needs of students. Wang and Wang (2014) argued from the perspective of "learning" that adaptive learning was to obtain learning content, way and path suitable for oneself through adaptive learning system. From the perspective of "learning tool support," Chandrasekaran et al. (1992) and Corbett and Anderson (1994) believed that adaptive learning was to model a knowledge system by combining the knowledge level of students with the intelligent tutoring systems based on knowledge and adaptive learning systems, and then recommend a knowledge construction route to them.

It can be seen that the early concept of adaptive learning is mostly from the perspective of traditional pedagogy, without highlighting the influence of intelligence and intelligent technology. With the continuous integration of intelligent technology, the research of "AI+ adaptive learning" has become a new proposition in international research, and adaptive learning has also been endowed with new meanings.

We believe that adaptive learning is an autonomous, intelligent, technology-driven and individualized learning approach guided by teaching and learning theories. Accordingly, adaptive learning system is an online learning environment or learning support/service system that integrates the concept of adaptive learning into it. The connotation of adaptive learning integrated with AI or intelligent technology is changing from "self-adaptation" to "intelligent adaptation," with new attributes different from the traditional meaning: autonomy, intelligence, individualization and adaptability.

Adaptive learning has two core words with iconic characteristics: "self" and "adaptation."

"Self" is first manifested as the learner's self-consciousness and autonomy, which emphasizes the student-centered autonomous learning. This kind of learning, different from passive learning, rote learning or indoctrination learning, is close to the visceral "meaningful learning" advocated by Ausubel (1960). "Self" is also embodied in the aspect of intelligence, that is, according to learners' self-characteristics, to automatically guide learners to deepen their cognition. It makes automatic recording of learning process, learning behaviors and learning results. According to the learning process data, it can automatically judge, automatically associate learning resource, automatically evaluate and automatically adjust learning strategies and learning behaviors. Hwang et al. (2020) pointed out AI-supported learning systems can simulate human intelligence to reason, judge or predict, not only to provide personalized guidance, support or feedback to students, but also to help teachers or decision-makers make decisions.

"Adaptation" is firstly manifested as individualization, that is, learners can independently choose their own learning methods and learning contents that meet their own development needs. In addition, learners can set their own learning schedule and learn in the most comfortable way, which fully demonstrates the "autonomous learning concept" advocated in the global framework of Education 4.0. "Adaptation" is also reflected in the dynamic mutual adaptation and constant adjustment between learners and learning environment, the difficulty of learning content, learning partners (including teachers) and learning technology, so as to find the balance point among various elements in adaptive learning. The more adaptable you are, the more comfortable the learning process is and the more efficient the learning process is, which is also different from the previous interpretation of "adaptive."

### 2.2. Adaptive learning system

Adaptive learning system, as an important carrier to support adaptive learning, has a close relationship with information technology. It can be said that the development of adaptive learning system has gone through six stages, including program teaching machine, computer-aided teaching, intelligent teaching system, intelligent agent teaching system, intelligent hypermedia teaching system and adaptive intelligent learning system. See Table 1 for details.

*Table 1*. The six stages of the development of adaptive learning system (Tang, 2020; Li, Dong, & Tang, 2020)

| Stages | Time | Whether or not smart | Man-machine interaction mode | Learning system expression mechanism | Learning path | Theoretical basis | Instructional design |
|---|---|---|---|---|---|---|---|
| Program Instruction (PI) | 1920s - 1960s | NO | Linear input/output | Knowledge showing | Preinstall | Behaviourism | Teaching-centered |
| Computer-Aided Instruction (CAI) | 1970s | NO | Linear input/output | Knowledge showing | Preinstall | Behaviourism | Teaching-centered |
| Intelligent Teaching System (ITS) | 1980s | AI | Multidimensional representation computing | Knowledge+ Induction | Preinstall | Behaviourism | Teaching-centered |
| Intelligent Agent Teaching System (Agent) | 1990-1996 | AI+ mass data | Perception | Knowledge+Data+ Computation+ Deduction | Preinstall +Recommendation | Cognitivism | Change from teaching-centered to learning-centered |
| Intelligent Hypermedia Teaching System | 1997-2011 | AI+ Mass data/ Big data | Perception +Lower cognition | Knowledge+ Mass data/ Big data+ Computing + Deduction | Preinstall +Recommendation | Cognitivism | Learning-centered |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (AEHS) | | | | | | | |
| | 2011-2017 | AI+ Big data | Perception +Lower cognition | Knowledge+ Big data +Cloud computing+ Deduction | Preinstall +Recommendation | | |
| Adaptive Intelligent Learning System | 2017- | AI+ Big data | Perception +Advanced cognition | Knowledge+ Big data +Cloud computing+ Deduction (Decision) | Preinstall +Recommendation | Cognitivism | Learning-centered |

In the 1950s, the programmed teaching proposed by Skinner can be called the germination of adaptive learning system; Computer Aided Instruction (CAI), which appeared in the 1970s, can be regarded as the prototype of the adaptive learning system. Pask in the UK developed the adaptive teaching machine using Computer, which is regarded as the primitive ancestor of CAI. Intelligent Tutoring Systems (ITS) emerged in the 1980s, and is often referred to as the earlier adaptive learning system, whose basic framework was proposed by Hartley and Sleeman (1973). In the 1990s, virtual reality (VR) and Agent technology were applied to ITS. Intelligent Agent teaching system, also known as intelligent student self-study software system, appeared. At the end of the 20th century and the beginning of the 21st century, the combination of artificial intelligence and Hypermedia technology has produced a new learning System, namely Adaptive Hypermedia System (AHS). In 1996, AEHS (Adaptive Educational Hypermedia System), developed by Professor Brusilovsky from the University of Pittsburgh in the United States, was called the first real Adaptive learning System (Brusilovsky, 1996). In recent years, with the continuous emergence of new technologies such as human-computer interaction, sentiment analysis and big data processing in online education, and the deep integration of artificial intelligence with educational science and psychology, the research on adaptive learning is deepening. Various adaptive learning systems have emerged, such as Knewton in the US, Knowre in South Korea, Smart Sparrow in Australia, online teacher training platform Declara, Cogbooks in the UK, Ape Test Bank, Classba Education and Homework Help in China.

Through the above six stages, it is not difficult to find that the research and application of adaptive learning systems generally present the following evolutionary trajectories. They are from intelligent teaching system to adaptive learning system, from non-intelligence to intelligence, from perception to cognition, from low-level cognition to advanced cognition including preliminary consciousness, from behaviorism to cognitivism, from preset learning path to learning recommendation, and from "teaching" as the center to "learning" as the center. By analysis of learning data, adaptive learning system adjusts learning content, knowledge assessment methods and knowledge sequence in real time, so as to meet learners' personalized needs.

### 2.3. Adaptive learning model

Over the years, the research and evolution of adaptive learning model generally presents a continuous deepening and expanding from system model to module component model.

**ITS model** is regarded as the predecessor of adaptive learning. Hartley and Sleeman (1973), a British scholar from the University of Leeds, proposed the basic framework of ITS. This framework includes three basic models: (1) Domain knowledge, namely Expert Model; (2) Learner knowledge, i.e., Student Model; (3) Teaching strategy knowledge, namely the Tutor Model. The framework theory of ITS constituted by these three models has become the classical theory guiding the design and development of ITS.

**AHS model** was proposed by Peter Brusilovsky (1996) from the University of Pittsburgh, USA, based on the framework model of ITS. It is the first general model of Adaptive Hypermedia system, also known as AEHS (Adaptive Educational Hypermedia Systems). The model is divided into four core components: domain model, pedagogy model, student model and interface module. The four components are connected through the adaptive engine, which makes personalized resource recommendation to students through the personalized mechanism.

Brusilovsky has done a series of fruitful work in the aspects of adaptive learning theory and technology, and is regarded as the pioneer in this field. In addition to the general model of AEHS, he also proposed the intelligent guidance system ITEM /IP (Brusilovsky, 1992), and the adaptive learning system such as InterBook (Brusilovsky, Eklund, & Schwarz, 1998), ElM-Art (Weber & Brusilovsky, 2001), Knowledge Sea (Brusilovsky & Rizzo, 2003) and Annotat Ed (Farzan & Brusilovsky, 2008).

At the same time, based on Brusilovsky's general model of adaptive learning (AEHS), extensive and in-depth studies have been carried out all over the world. Wolf of RMIT University in Melbourne had designed and

developed an adaptive learning environment using Java programming language - iWeaver, which uses the Dunn Learning Style Model (Wolf, 2003). Papanikolaou et al. (2003) from the University of Athens designed and developed a personalized education hypermedia system INspire, which generates course content according to learners' cognitive level and learning style. Alrifai et al. (2012) from the University of Hannover in Germany studied the user and domain model of adaptive learning system. Eindhoven University of Technology in the Netherlands developed an open source adaptive hypermedia system Aha!, which modified the user model and added new functions (AHA!, 2020). Wang, Zhao and Wei (2019) designed Mindolm, an open learner model, in the form of mind mapping visualization.

With the deepening of related researches, the functions of adaptive learning system model and component model become more and more rich. The system model develops from linear guidance to nonlinear guidance and from one-way broadcast to two-way interaction. The knowledge content of domain knowledge model develops from coarse granularity to fine granularity, the learner model develops from previous knowledge state analysis of students to learner style and emotion analysis, etc.

In our opinion, although many different models have been proposed, most of the researches on adaptive learning models are still based on AEHS model, which has not broken away from the traditional research pattern and has not achieved breakthrough progress.

### 2.4. Key technologies and algorithms of adaptive learning

Different adaptive learning systems may have big differences in their function realization and content display. Generally speaking, there are three main ways to realize adaptive learning: adaptive content selection, adaptive navigation support, and adaptive content presentation (Brusilovsky, 2012; Romeroc & Zafraa, 2009). Nowadays, the new generation of adaptive learning system breaks the limitation of the traditional intelligent learning system that all students have the same learning path, and can create a customized learning content and learning path according to the learner's own state, namely learning data. And optimized learning programs are recommended to learners and personalized learning guidance is provided to learners that is different from others. The realization of this function mainly comes from the key technology and algorithms adopted by the system.

#### *2.4.1. Key technologies*

The key technologies to truly realize personalized learning demand and learning pushing function mainly include data mining, learning analysis, machine learning, knowledge mapping, cognitive expert consultant, learning recommendation, edge computing, virtual reality, etc. The most commonly used adaptive learning techniques include Web application mining and text mining, semantic web ontology technology, fuzzy logic, etc. Romeroc and Zafraa (2009) integrated a specific Web mining tool and recommendation engine into AHA! The system helps teachers carry out the whole Web mining process, in the AHA! The system provides the most appropriate link page for students. Vesin et al. (2012) developed Protus2.0, an intelligent teaching system for learning programming languages, based on semantic web ontology technology, to create learner ontology, domain knowledge ontology, learning task ontology and teaching strategy ontology, and designed adaptive rules for reasoning to achieve personalized teaching. Chang et al. (2009) proposed a classification mechanism based on learners' Learning styles, optimized the K-Nearest Neighbor (KNN) classification algorithm, and combined it with GA (Gene Algorithm) algorithm and applied it in the open learning Management System, which could accurately and efficiently determine learners' Learning styles. Chrys Af Iadi and Virvou (2012) uses Kirkpatrick model and hierarchical evaluation method to evaluate the knowledge level of students, and uses fuzzy logic technology to define and update the knowledge level of students for the evaluation of ITS C language programming.

#### *2.4.2. Algorithms*

Xu Kun (2020) combined with several adaptive learning platforms such as Kenton, Assissment and VIPKid, summed up three basic algorithms of adaptive learning: (1) Bayesian knowledge tracing. When tracking learners' mastery of knowledge points, Bayesian inference algorithm is used. (2) Bayesian network. Its basic structure is directed acyclic graph by analyzing, mining and modeling various association of learning data, so as to infer the path of students' learning evolution. These two Bayesian algorithms are collectively called probabilistic graph modeling. (3) Some technologies and methods in the field of educational measurement, such as Item response theory and Learning space theory. This algorithm can accurately locate the current knowledge level and learning

state of students for learning diagnosis and recommendation. In practice, these three basic algorithms are often expanded or combined to meet the specific needs.

### 2.5. Other aspects of adaptive learning research

In recent years, the development of artificial intelligence (AI) has affected all areas of human life. The educational application of artificial intelligence has been widely concerned. AIED (Artificial Intelligence in Education) has been identified as the main research focus in the field of computer and Education (Chen, Xie, Zou, & Hwang, 2020; Hwang, Xie, Wah, & Gašević, 2020). AI-supported learning systems can simulate human intelligence to reason, judge or predict, not only to provide personalized guidance, support or feedback to students, but also to help teachers or decision-makers make decisions. Hwang, Xie, Wah, and Gašević (2020) proposed a framework to show the considerations of implementing AIED in different learning and teaching settings. The structure can help guide researchers with both computers and education backgrounds in conducting AIED studies. Chen, Xie, Zou, and Hwang (2020) evaluated definitions of AIED from broad and narrow perspectives and clarified the relationship among AIED, Educational Data Mining, Computer-Based Education, and Learning Analytics. Chen, Xie, and Hwang (2020) presented multiple perspectives on the development of AIED, and provided an overview of AIED for its further development and implementation. Zou & Xie (2018) developed a system based on Nation and Webb's checklist for technique feature analysis. This system recommends personalized word learning tasks based on the technique feature analysis scores of different tasks and user models. Based on human-computer collaboration, Li et al. (2019) proposed the construction method of knowledge graph in adaptive learning system, and took "artificial intelligence" discipline as an example to preliminarily verify the construction method.

In addition, from Interbook (Brusilovsky, 1998) in 1996, which focused on the personalized learning behavior of learners, to Cogbooks in 2015, which emphasized diversified analysis based on the personalized needs of learners, it can be seen that the adaptive learning system aims to continuously improve the learning process of students, provide interactive instructions in an automatic way, and provide learning support for learners anytime and anywhere (Walkington, 2013). Qiu, Zhao and Liu (2008) established the ontology of user model with text editor in 2008, and formed the database of user model. Jiang, Zhao and Wang (2011) adopted ontology technology to design the reference specification for establishing user model and knowledge model. Liu (2011) proposed the method of constructing the domain model and the corresponding design strategy of the process based on semantic network. In the study of mathematics, Ven et al. (2017) designed a tablet computer game, which can effectively help students improve their arithmetic ability of addition and subtraction. Stein (2019) emphasized that the biggest obstacle to personalized learning at present was the development of pedagogical theories to guide adaptive learning systems (Cui & Xu, 2019).

In the face of the current intelligent era, "digital generation" learners are increasingly pursuing diversified, personalized and comfortable learning needs, learning styles and learning scenarios, etc., and their requirements for learning analysis, learning evaluation and learning recommendation based on adaptive learning are also getting higher and higher. Therefore, we need to continue to explore new adaptive learning systems and applications.

## 3. Method

The purpose of this study is to analyze and summarize the research trend and existing problems of adaptive learning in the world in recent years, and find out the path and method to solve the problems.

### 3.1. Data source

The data of statistical analysis are mainly from the library of Shanghai Jiao Tong University, and the data collection is comprehensive. In the library of Shanghai Jiao Tong University, the collections are rich, and the quantity and quality of its electronic resources are among the best in China. Through the Shanghai Jiao Tong University Library - the entrance to the databases, CNKI and Scopus are selected, including full text of journals, full text of important newspapers, full text of important conference papers, full text of doctoral dissertations, full text of master's dissertations and other sub-databases.

### 3.2. Research method

The research includes academic literature retrieval, selection of retrieval results and analysis of sample data. Based on the literature database mentioned above, using "adaptive learning" as the key word, the retrieval scope was from 1971 to 2020, and the retrieval time was October 30, 2020. A total of 8,688 related literatures were retrieved, including 5,607 foreign literatures and 3,081 Chinese literatures. For those with repeated contents, the paper with the most complete data was selected after being judged to be the same study. A total of 7,880 papers in Chinese and English were detected after excluding unrelated papers, removing the duplicates and removing the literatures with unclear information sources and incomplete data. Because the library classifies "adaptive education," "intelligent education," "personalized learning" and other related concepts into "adaptive" learning category automatically, in order to comprehensively and accurately retrieve the required documents and avoid the exclusion of some relevant documents by the "precise" retrieval mode, this paper does not adopt the advanced precise retrieval mode with more retrieval conditions. Since the purpose of the analysis is to deeply understand the overall research trend of adaptive learning and the current problems encountered in the research of adaptive learning, the research mainly focuses on and analyzes the literature state and research problems in the recent 6 years from 2015 to 2020. Therefore, along with decades of research results, combined with the author's research, reflection on the development and trend of adaptive learning has both support and guarantee.

### 3.3. Coding

The qualitative data coding method is used to process the data. Firstly, open coding is carried out for the researched problems, and all the problems related to adaptive learning are extracted. Then, spindle coding is made based on open coding. Finally, according to the researched questions, "core categories" are found out to complete the selection coding.

## 4. Results

### 4.1. Research trends in adaptive learning

By the literature quantity analysis, the research trend of "Adaptive Learning," namely the trend chart of academic attention, is obtained, as shown in Figure 1. It can be found that the research trend of adaptive learning is on the rise on the whole. Early international attention on adaptive learning began before 1971, and the number of literatures increased year by year. From 2008 to 2019, the number of literatures showed an obvious upward trend of fluctuation. Especially from 2015 (454 articles) to 2019 (836 articles), the attention of the past five years has risen sharply, and the peak is reached in 2019. In 2020 (736), there is a slight decrease compared with 2019, and the difference is negligible. It has two reasons. One is the cause of the epidemic, and the other is incomplete data. This shows that adaptive learning has become a research hotspot in the academic field in recent years.

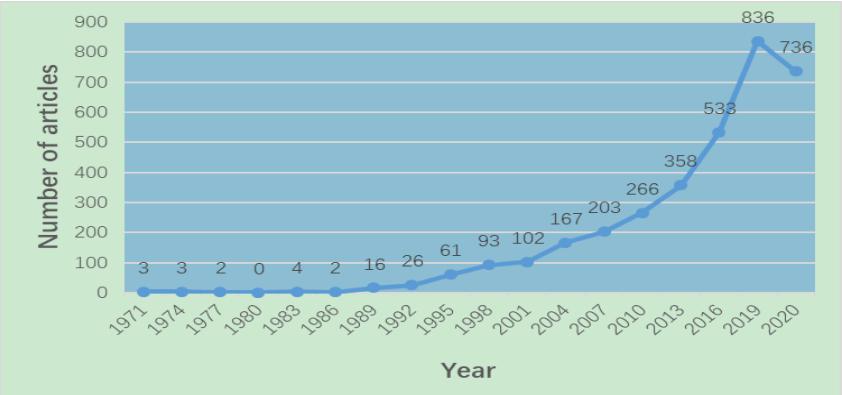


*Figure 1.* Academic attention on adaptive learning

Based on CNKI platform, with the theme of "adaptive learning research," we used the measurement visualization analysis software inside CNKI platform to carry out the keyword co-occurrence network analysis and obtained the keyword co-occurrence network graph of self-adaptive learning research, as shown in Figure 2. It is found that the frequency of keywords such as neural network, adaptive learning system, personalized learning, adaptive control, machine learning and some algorithms is high, which indicates that the relationship between modern adaptive learning and artificial intelligence is very close.

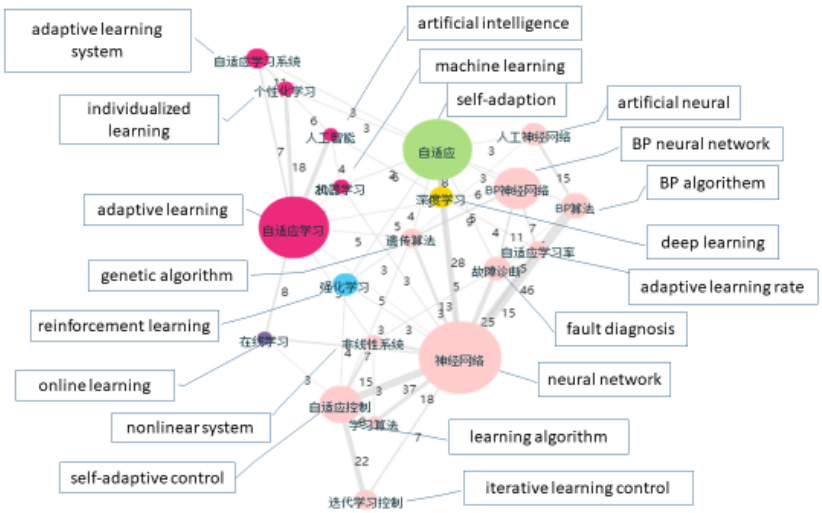


*Figure 2.* Adaptive learning studies co-occurrence networks of keywords

### 4.2. Challenges in adaptive learning research

Through literature analysis, at present, the research on adaptive learning at home and abroad is undergoing a process of development and evolution from coarse to fine, from whole to module, and from theory to demonstration (Wu & Chen, 2018). From the microscopic point of view, from 2015 to 2020, there are 209 "problem research" literatures. It shows that there are still many difficulties and challenges in the study of adaptive learning. For example, there are more theoretical studies, less empirical studies, and less mature system platforms (Chen, Xie, Zou, & Hwang, 2020). There is a gap between theoretical research and practical application, and the practicability of research results is poor. (Xu & Wang, 2011; Chen, Xie, Zou, & Hwang, 2020). The data analysis results are as follows (Xie, Chu, Hwang, & Wang, 2019).

*Table 2*. The topic distribution of adaptive learning literature research "problem research"

| Themes | Frequency | Proportion（%） |
|---|---|---|
| Concept, understanding, policy | 35 | 7 |
| Technical problems | 111 | 21 |
| Disciplinary fragmentation | 62 | 12 |
| Emotional modeling | 45 | 8 |
| Data management | 58 | 11 |
| Privacy disclosure | 42 | 8 |
| Classification of knowledge points | 37 | 9 |
| More theoretical studies, less empirical studies | 120 | 22 |
| Others | 22 | 4 |

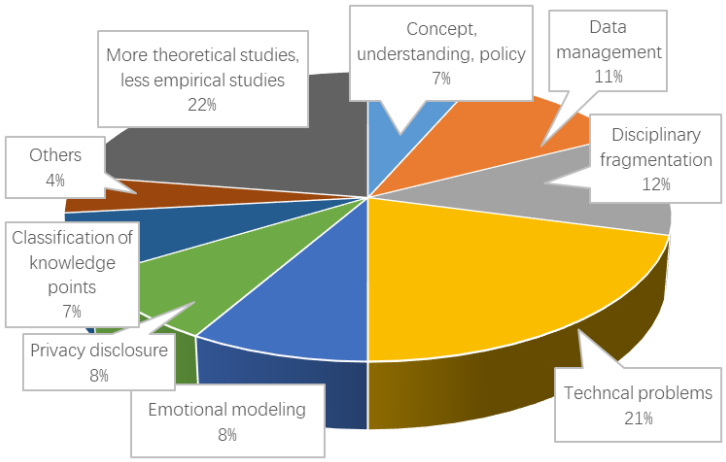


*Figure 3*. The topic distribution of adaptive learning research literature "problem research"

Outstanding performance in these problems: vague concept and unclear understanding (35), poor flexibility or technical issues (111), disciplinary fragmentation (62), modeling bottlenecks of emotion domain (45), learning data management (58) , privacy security (42), broad classification of knowledge points (37), much theory but little practice (120) and others (22). The distribution is shown in Table 2 and Figure 3.

#### *4.2.1. Cognitive bottleneck*

Current research on adaptive learning lacks systematic and holistic cognition of learning, which is embodied in the following aspects: adaptive learning system is "clumsy," not so "intelligent," and cannot "follow one's inclinations" to realize our learning ideas.

Due to the limitation of people's cognition of the brain (Wu, 2020), the current artificial intelligence technology cannot meet the requirements of adaptive learning system. Although people have a clear understanding of the information transmission and processing principle of some neural circuits in the brain, as well as the mechanism of primary sensory function, the cognition of the global information processing, coding and learning principle of the brain is still very limited. The mathematical principles and computational models of information processing in the brain are still unclear (Wu & Pan, 2020). Therefore, the adaptive learning technology based on "artificial intelligence" which simulates brain function cannot achieve full intelligence, individuation and adaptability just like interpersonal communication.

Another misconception is the "technological omnipotence theory," which holds that artificial intelligence is powerful enough to meet the requirements of adaptive learning systems (Nichols, 2020). Artificial intelligence has far more storage and computing power than the brain. For example, AlphaGo had beaten the human champion. However, training people is not the same as training machines. At the same time, in the face of huge courses and different knowledge systems, adaptive systems and platforms are difficult to cover all aspects. The narrow scope of knowledge contained by adaptive learning system will make adaptive learning lose part of its advantages in the development of future education world (Nichols, 2020). In addition, in the traditional adaptive learning mode, the logic of jump between different learning contents is linear and single. Even if students have mastered a certain content, they still need to spend time to learn it. What's more, students can't get immediate feedback or help when they have problems. Learning is a complex and implicit process, and simple computer programming is difficult to achieve good results.

#### *4.2.2. Disciplinary fragmentation*

A relatively perfect adaptive learning system often needs the close combination of theoretical guidance and technical implementation, and requires the cooperation of experts in many fields to complete. The realization of educational theory and method needs technology, which needs the guidance of educational thought. The reality is that there is a split between disciplines, particularly between educational science and computer science. The technical realization experts of adaptive learning system are mostly experts in the field of computer. Due to the lack of educational theory and personalized learning theory, it is difficult to design a learning system that conforms to the teaching law and learning law and is suitable for the personalized development. However, due to the lack of professional computer technology, scholars in the field of education are also unable to convert the concept of adaptive learning design into products (Xu & Wang, 2011; Wu & Chen, 2018). Hinton believed the key to overcoming the limitations of artificial intelligence was to build a bridge between computer science and biology (Somers, 2017).

#### *4.2.3. Lack of learner emotion modeling*

Learning is a complex and hidden process, people do not have the storage and computing power of a computer, but have seven emotions and six sensory pleasures, with complex physical and psychological performance, and these performance will have a complex impact on the learning experience. However, the traditional human-computer interaction is mechanical and difficult to meet the emotional needs of learners. At present, deep learning has been used to study emotion classification, but its achievements in natural language processing are not obvious, especially in the field of adaptive learning, there is no breakthrough. Adaptive learning should consider learners' starting ability, learning style and emotional state, etc. However, the current system cannot understand learners' emotions and cannot truly realize adaptive learning (Hu & Chen, 2018). Therefore, it is necessary to establish an adaptive learning algorithm and model that can fully understand the brain thinking and psychological emotions to perform human tasks. However, this emotion modeling process based on artificial intelligence is quite difficult and lacking (Cui & Xu, 2019).

#### *4.2.4. Flaws of centralization management of learning data*

The current adaptive learning systems, such as Knewton and Knowre, mostly adopt the centralized server management mode (Huang, Liu & Xue, 2020), which has three obvious deficiencies. First, this centralized service model is easy to be manipulated by others, which easily leads to the disclosure and attack of privacy and important data in the process of data analysis. Second, a large amount of learning data is unique to some institutions, which is easy to form Matthew Effect, resulting in difficulties in data collection and sharing, while adaptive learning analysis requires massive data and data sharing among different institutions and platforms. Third, centralized data interaction and management affect learning efficiency.

#### *4.2.5. Data security and privacy breaches*

Personalized learning is an important feature of adaptive learning. In order to achieve personalized and adaptive needs, the server of the adaptive learning system should collect and analyze the personal information of learners, such as learning interest, starting point level, learning style and emotional state. Adaptive learning evaluation also needs to collect learners' learning performance, learning process and the types of resources used by learners (Hu & Chen, 2018). After data collection, these learning data need to be analyzed before individualized recommendation of learning content and learning partners can be made. Otherwise, the learning process cannot be automatically customized, nor can personalized services be provided. In the process of learning data analysis, the privacy of learners, the security of learning data and the right to use will be involved (Cui & Xu, 2019).

In addition, with the development of artificial intelligence, many institutions at home and abroad try to develop a variety of intelligent teaching and learning systems. The technology covers a wide range, the market is uneven, and there is a lack of unified standards and evaluation mechanism (Wu & Chen, 2018). They develop independently, and many data, algorithms and technologies are exclusive to the organization, resulting in Matthew effect. Theory and technology are of low level and high repetition (Chen, 2003), and almost no online platform can truly realize adaptive learning.

## 5. Discussion and Conclusions

### 5.1. Discussion

In view of the outstanding problems of intelligence, adaptability and privacy in adaptive learning research, we propose the following strategies from the aspects of cognition, technology and education combination, emotional breakthrough, learning data management and privacy protection.

#### *5.1.1. Cognitive breakthrough*

(1) Cognitive breakthroughs in the brain, combining technology and brain science

In order to achieve intelligent, adaptive and personalized functional requirements, the adaptive learning system needs to understand the learning process of human beings and the thinking process of human brains. The first step is to understand the mathematical principles and computational models of brain information processing, that is, to build computational models that can perform cognitive tasks and explain brain information processing. Therefore, it is necessary to deeply understand the mechanism of the input, transmission, exchange and output of human brain information, that is, how to produce various brain cognitive functions such as sensation and perception, emotion, choice and language. In addition, it is important for us to fully understand the information cognition and processing process of human brain. At present, people's understanding of the brain is still very limited, so it is necessary to rapidly develop the synchronization technology of information acquisition between whole brain cognition and local response (AHA!, 2020). Only by fully recognizing the brain can we achieve the breakthrough of adaptive learning technology.

(2) Cognitive breakthroughs in technology, developing zones of proximal development of technology

On one hand, we should be clearly aware that technology is not everything. A man does what a man should do, and a machine does what a machine should do. Therefore, no matter how advanced the adaptive learning system can weaken people's thinking ability. We cannot use the intelligence of the machine to train people into a

uniform robot with the same intelligence, nor can we at the cost of human's hard work to train their own next generation into a fool at the mercy of the machine. Machines are meant to serve people, not replace them. The purpose of man-machine cooperation, in the final analysis, is to improve the quality of human life and learning effects.

On the other hand, there has always been a gap between theoretical research and practical application. According to Vygotsky's zone of proximal development theory, a reasonable technical step is set. Based on the current successful cases, adaptive learning technology needs to focus on solving two problems.

Firstly, change the deterministic learning structure to the non-deterministic learning structure, as shown in Figure 4. Traditional intelligent teaching systems and most of the current so-called "adaptive" learning systems are based on a preset learning path, and the students' learning path is almost the same. In this regard, adaptive learning should be committed to detecting students' current learning level and status through computer means, and adjusting subsequent learning contents and paths accordingly, so as to help students improve their learning efficiency. Therefore, adaptive learning realized by using artificial intelligence technology is an upgrade of traditional adaptive learning and an exploration of new learning methods. Only by changing the deterministic learning structure to the non-deterministic learning structure, different learners have different learning paths, and then personalized learning needs can be realized.

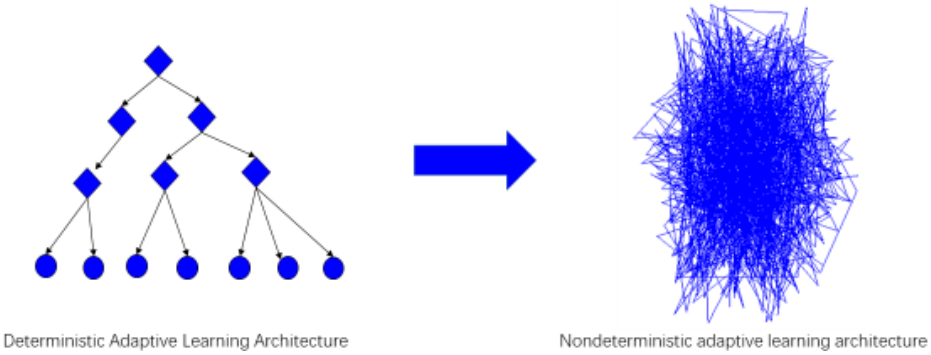


*Figure 4*. Adaptive learning architecture evolution

Secondly, the labeling system of knowledge points will be further improved. Only the classification of knowledge points is more detailed, the accuracy will be higher and the adaptability will be stronger. For example, the interactive teaching and learning scene of the adaptive learning calligraphy system jointly developed by our team in cooperation with Shanghai Gusuo is shown in Figure 5. The system has stored a large number of calligraphy teaching resources, including expert writing demonstration videos, famous masters' classroom videos and ancient inscriptions, including more than 60,000 inscriptions, a calligraphy library of more than 20,000 words, a calligraphy collection of more than 20,000 words, more than 10,000 videos, and 18 sets of self-developed intelligent courses. The knowledge points are subdivided into stroke, side, structure, examples and lines of writing, stroke order view, stroke position view, single hook view, double hook view, the original drawing of the tablet and other detailed content. The system can not only realize the real-time interaction between teaching and learning, but also record the learning data to the cloud synchronously. The system recommends different learning contents and paths according to students' actual level and personality differences. Students can also study independently according to their own needs. The system also sets up some experiential learning games to improve students' interest in learning and solve the problem of low efficiency in traditional calligraphy teaching and learning from multiple aspects and angles.

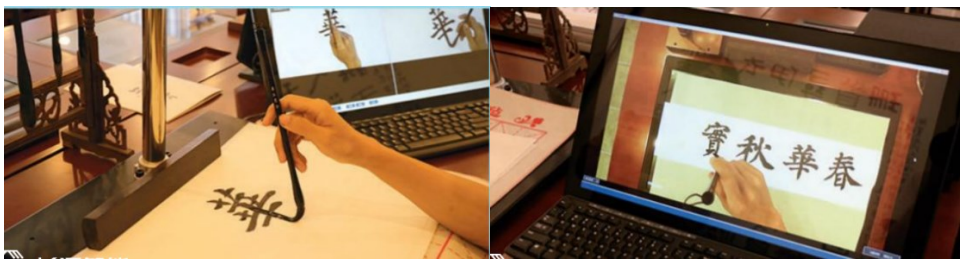


*Figure 5*. Adaptive learning calligraphy system teaching and learning interactive scene

### *5.1.2. Integration of technology and education*

Adaptive learning serves learners with distinct personalities. The realization of adaptive learning needs technical support. Education has the law of education and technology has the logic of technology. However, technology is only an auxiliary means of learning, not the whole. We shouldn't rely too much on its value and effects. AI has trained Deep Blue, AlphaGo and Gaokao Robots by machine learning that surpass human beings. But we can't use machine learning to train humans. The design of any learning system should respect the essence of education, because people have the unique characteristics of human beings, including emotions, thoughts, and specific teaching rules and methods. Human characteristics and educational rules should be fully considered in the study of adaptive learning.

Educating a person is a continuous emotional process. Currently, existing AI products include Chinese tools such as photo search, hierarchical class arrangement and oral assessment, which can assist a certain learning process, but will not directly improve the quality and effect of teaching. Adaptive learning products can help to fundamentally improve the concept and way of learning only when artificial intelligence technology penetrates into each core link and the whole process of teaching.

Adaptive learning products' developoment needs cross-boundary collaboration and joint exploration from multiple fields and disciplines, including teaching and research experience, pedagogy, psychology, computer, big data and artificial intelligence.

### *5.1.3. Multi-domain integration of emotional breakthrough*

A breakthrough approach is discipline integration. It is not only the integration of information technology and education, but also needs to be closely combined with brain science, psychology, statistics and other major disciplines, so that adaptive learning research can have a greater chance to make breakthroughs.

The various learning processes are interacted through polymorphic communication. The more data on the platform, the more accurate the pushing results will be. Current adaptive learning systems pay too much attention to knowledge and skills themselves, which can improve learners' speed of mastering knowledge points and test-taking ability, but it is difficult to meet human emotions and values needs. We already have millions of kinds of knowledge sample data, but the sample data on human emotions is very small, especially the data on human spirit, value and soul is almost zero (Wang, Zhao, & Wei, 2019). Therefore, strengthening the collection and sharing of the underlying data samples, especially the data of emotional value, will become the focus of the next research.

### *5.1.4. "Code chain" management mode of learning data*

In view of the deficiency of the centralized server management mode of adaptive learning system, we first put forward the concept of "code chain" to solve the crisis of distributed processing of learning data. Code chain is the integrated innovation of graphic code technology and block chain technology. The code of "code chain" is intelligent stereo graphics code, referred to as intelligent code; and the chain of the "code chain" is equivalent to the "chain" of the traditional blockchain.

Blockchain has the advantages of distributed, decentralized, irreversible and anonymous, but it has many drawbacks, such as expansion, efficiency and security issues. The combination of smart code and blockchain is a good choice.

Intelligent code is a kind of graphic code similar to two-dimensional code, but it is better than two-dimensional code. It is essentially different from two-dimensional code. Intelligent code is to replace binary data "0" and "1" with geometry or graphics, as the text of communication between man and machine, machine and machine, in the form of three-dimensional interwoven curve geometry (graphics) for information storage, transmission and display; Geometric algorithms and structured encryption are used to manipulate storage, transmission, and interpretation of information. In the course of data collection, storage and transmission, it is convenient, decentralized, multi-dimensional and variable, personalized customization, naked eye recognition, accurate interpretation, deep encryption, intelligent anti-counterfeiting, anti-copying and traceability. The "code" in "code chain" replaces each node and block in the blockchain for distributed acquisition, storage and transmission of learning data. In addition, the code has the function of learning data security and traceability, as shown in Figure 6.

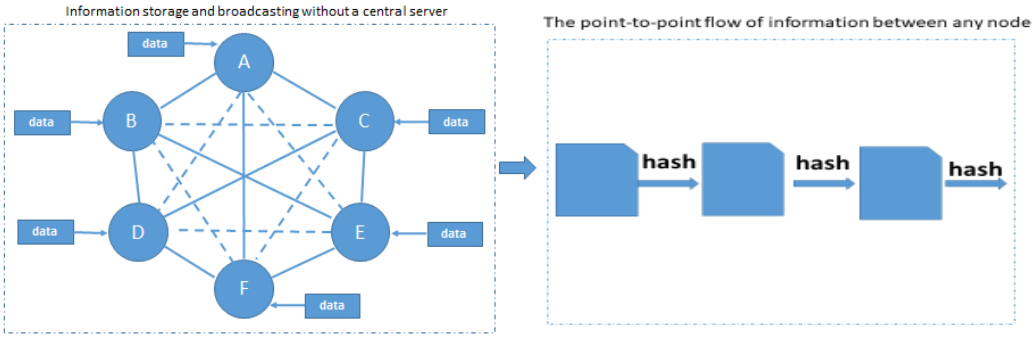


*Figure 6*. Decentralized data processing pattern of code chain

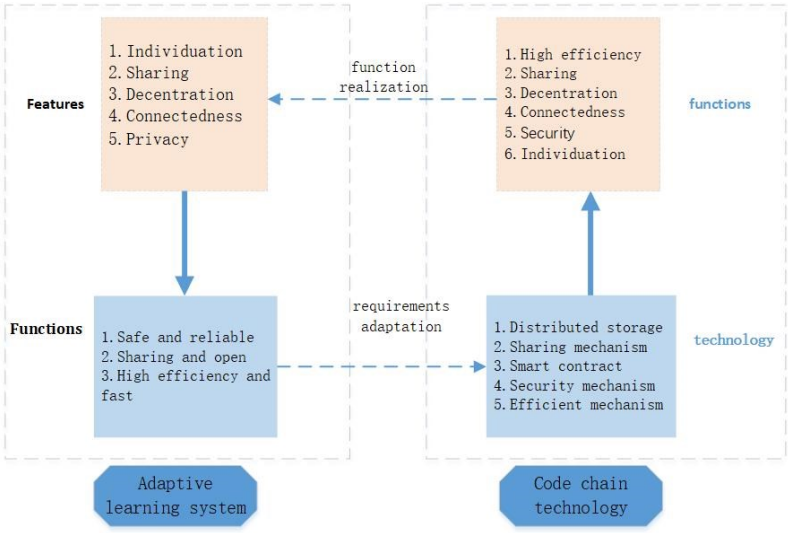


*Figure 7*. A way of integrating code chain technology into adaptive learning

The code chain technology compatible with the advantages of smart code and block chain is integrated into the adaptive learning system, which has the following advantages: (1) High efficiency. The acquisition of learning data is convenient and quick, the storage and transmission of learning information is larger, and the learning efficiency is improved. (2) Personalized and traceable. It can record each learner's learning process, grades and other evaluation results in the whole process. (3) Shared. Code chain technology can distribute data and computation to shareable network nodes around the world. In addition to users' private information encrypted, any learner can get the whole network data and complete backup. All participants can also get learning resources shared by different institutions or platforms, which solves the difficulty of data collection and sharing. (4) Decentralization. Without a central server, learners can establish trusted data interaction by point-to-point network communication protocol, realize distributed storage and decentralized management of learning data, and improve learning efficiency. (5) Connectivity. Each node on the code chain can maintain connectivity regardless of whether it is in the same platform and organization, which is convenient for learning data and learning resources sharing, learning content and learning peer recommendation. (6) Privacy. Each learner participates anonymously, without the need for public identity, which reduces the risk of disclosure of learners' personal information (Li, 2019).

The reason why code chain can serve adaptive learning system is that code chain technology can provide key support for adaptive learning data management and meet the functional requirements of efficient and safe learning of adaptive learning system. The way of integrating code chain into adaptive learning is shown in Figure 7.

It can be seen that with the help of code chain technology, the adaptive learning system can change from centralized to distributed, and can better realize the sharing, circulation and management of learning data in a decentralized environment.

### *5.1.5. A new adaptive learning pulling model*

The principle of artificial intelligence adaptive learning builds learning models and outputs learning suggestions on the basis of Big data. At the present stage, "collecting big data -- building learning models -- outputting learning suggestions" is basic procedure to realize adaptive learning of artificial intelligence. The construction process of learning model is very complex. First of all, it needs to find out learning rules from a large amount of learning data and infinite function nesting relations. Secondly, the model is constantly trained and optimized. Finally, the study recommendation and prediction are made. The more time students spend in using the system, the more behavioral data they leave behind, and the more efficient the system becomes.

One of the core technologies of adaptive learning is learning recommendation technology. Through machine learning method, learners' personal information, learning process data, learning style and emotional state are analyzed, and then suitable learning content or learning plan is recommended to learners.

(1) The traditional recommendation model of adaptive learning

At present, the learning analysis of the adaptive learning system is all conducted on the server side. This process inevitably involves the privacy of learners, the security of learning data and the right to use, as shown in Figure 8. To solve this problem, we design a new type of machine learning security model.


*Figure 8*. The traditional recommendation model of adaptive learning

(2) A new adaptive learning pulling model

Different from the traditional adaptive learning recommendation model, we design a new adaptive learning pulling model using machine learning and data pulling technology, as shown in Figure 9. "Adaptive learning pulling" contains two connotations. One is that it is different from the current use of adaptive learning recommendation system on the server side of the implementation of learning analysis, learning analysis of the adaptive learning pulling model can be implemented in the client, i.e., the learner's computer or handheld mobile terminal. The other is that learners have a certain ability to select the recommended information, and can remotely "pull" the information recommended by the server, which is the learning content they are really interested in or need. It is divided into the following five steps:

Step 1. The learning data does not need to be uploaded to the Internet. The AI data analyzer realizes personalized analysis of learners on the student side.
Step 2. The AI data analyzer will transmit the analyzed data to the filter and display device. Learners can filter and edit the menu of learning needs according to their own actual learning needs. Unneeded learning items can be deleted, and then the system will automatically submit them to the intelligent assistant.

Step 3. The intelligent assistant blindly processes the personal information of learners and upload only learning needs to the server of the adaptive learning system as an agent.

Step 4. The adaptive learning server calculates according to the needs of the intelligent agent, and then transfers the relevant learning content or learning scheme to the intelligent agent to complete the learning pulling. At this stage, the server does not need to know who the learner is.

Step 5. The intelligent agent transmits the pulling results to the filter and display, and present them to the learner.

The "decentralized" adaptive learning pulling model has obvious advantages over the traditional learning recommendation model. First, learning analysis takes place on a student side, reducing the risk of privacy breach. Secondly, the learning analysis is not focused on the adaptive learning server, but distributed on each student side, which reduces the pressure on the server and improves the efficiency. Moreover, it selectively recommended the necessary learning content and screened out the unnecessary junk information.

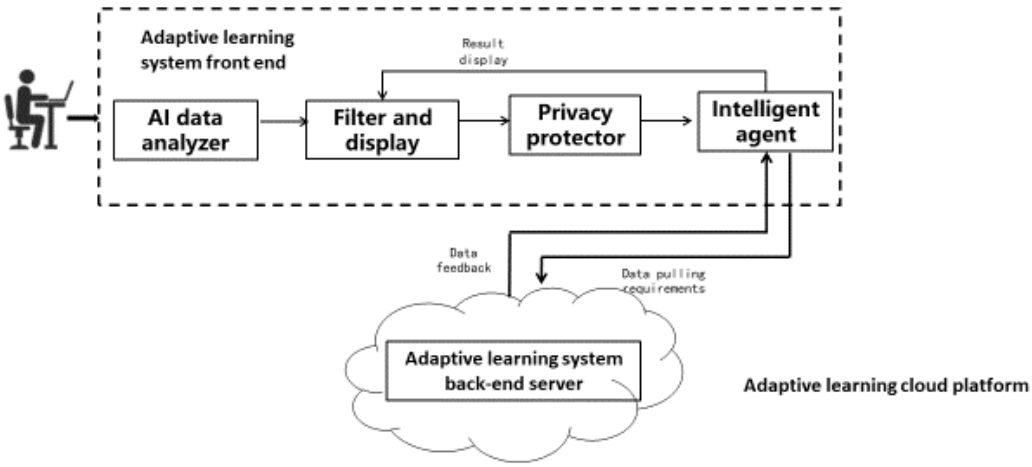


*Figure 9*. A new adaptive learning pulling model

### 5.2. Conclusions

Adaptive learning helps to realize personalized and autonomous learning, and is an important development direction of both online education and learning science. For more than half a century, scholars at home and abroad have done conducted extensive research on intelligent teaching and adaptive learning, and acquired a large number of achievement. However, there are still many shortcomings. Based on the systematic analysis of the connotation and progress of adaptive learning, this paper gives a new definition of adaptive learning. By literature analysis, it also discusses the major challenges of adaptive learning research, such as the lack of both knowledge of brain and technology, the bottleneck of emotion domain model, the separation of education and technology, the security and privacy risk of data management. The above challenges can be summarized into two aspects: one is mechanical, and the other is privacy. Different from the traditional perspective of adaptive learning, we open a new window and put forward some countermeasures from the perspectives of cognitive principle, learning data management and learning data security. In view of the current adaptive learning centralized management, the concept of code chain and decentralized management mode based on code chain are proposed. Different from the traditional learning recommendation technology, a new learning data pulling model based on privacy protection is proposed.

Due to the current cognitive limitations of artificial intelligence and brain learning, the research of adaptive learning is in the primary stage of development, waiting for the iterative update of theory and technology. In order to realize individualization, intelligence, autonomy, adaptability and security, it needs continuous attention of researchers, cross-integration of multi-disciplines and multi-fields, collection and sharing of massive data, and consideration of personal privacy.

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