The Historical Development of Deep Learning and Its Research Trend: A Literature Review

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Abstract: Deep learning has recently received unprecedented attention from governments, schools, social institutions, and the media. The puspose of this study is to present an in-depth understanding of relevant research published in top-tier journals from 1976 to 2019 through a systematic review method.

The results reveavled: (1) four phases of deep learning research: dormant period, germination period, emerging period and rapid period; (2) the deep learning research is concerned more about process, little discussion on flexibility; (3) the concept shifted in two directions, one is from the pursuit of understanding to the pursuit of transfer and the other is from the focus on process to the focus on outcomes. Based on the findings, this study proposed a landscape to the concept of deep learning to deliever a full understanding of the deep learning and we suggest more research should focus on the problem of deep flexibility with the empowerment of smart classrooms.

Keywords: concepts evolvement; deep learning; learning architecture; literature review; research trend; smart classroom

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Influenced by the concept and framework of core literacy education, the deep learning movement has emerged. In addition, a series of education and teaching reforms triggered by information technology, especially AI technology, deep learning has once regained the wide attention of the academic community and the general public, especially at the time when machine defeated Lee Sedol, the world champion of Go. Deep learning in education has received unprecedented attention and recognition from governments, schools, social institutions, and the media (Zhu, & Peng, 2017). Currently, deep learning now is extremely valued among the school leaders (Johnson et al., 2014), and the shift to deep learning has also become a long-term trend driving the application of educational technology (Freeman, Adams , &Cummins, 2017). How to promote students' deep learning and cultivate their deep learning abilities has been an increasing important topic for an education reform.

Deep learning is not a newly emerging concept. Since 1976 when it was first time proposed, deep learning has experienced more than 40 years ‘ development and evolution. While there is little discussion regarding how deep learning developed, how the concept evolved, what are the current research bottlenecks we might need to focus on and what are the potential solutions, this study is to explore those questions and hope to help scholars and teaching practitioners construct a

comprehensive understanding of deep learning and accurately grasp the orientation of deep learning research and development. By using a systamacti review method, this study deeply reviewed articles indexed in SSCI ranging from 1976 to 2019.

1.Literature Sources and Analysis Methods

According to the literature dispersion theory of most key literature is usually concentrated in a few core journals, this study uses the paper title names of "deep(er) learning, deep approach(es), deep strategy/strategies" to search articles indexed in SSCI on the Web of Science database. The obtained documents are selected according to the following selection criteria (Petticrew, &Roberts, 2006): a) not a duplicate article, b) the topic should be about education and teaching, c) the publication date is between 1976 and 2019. A total of 109 arctiles were included for the further analysis.

First, the trend of deep learning research popularity was explored using econometric analysis and visualized through social network centrality analysis. Content analysis was used for an in-depth understanding of the research bottleneck and possible solutions of deep learning. The social network centrality analysis was carried out according to the following steps: a) data cleaning (e.g., term unification); b) importing keywords of the literature into BICOMB2 software for a word frequency analysis; c) generating co-occurrence matrix through co-occurrence analysis of high-frequency keywords with word frequency greater than or equal to 3; d) importing co-occurrence matrix into UCINET6 software for the social network centrality analysis using the NetDraw tool.

2.The trend and status of deep learning

Content analysis results show that international scholars generally believe that the concept of deep learning was first proposed by Maton and Säljö in 1976, even though they did not use the term, deep learning. In fact, this term was gradually adopted after the 1990s, and the earliest user was the scholar Valerie Malhotra Bentz (1992).

2.1. The trend of deep learning research

Econometric analysis shows (see Figure 1) that deep learning has not been widely concerned by scholars until 21st century. Throughout the history of deep learning research, the trend of deep learning research has gone through four periods: dormant period, germination period, emerging period and rapid period.

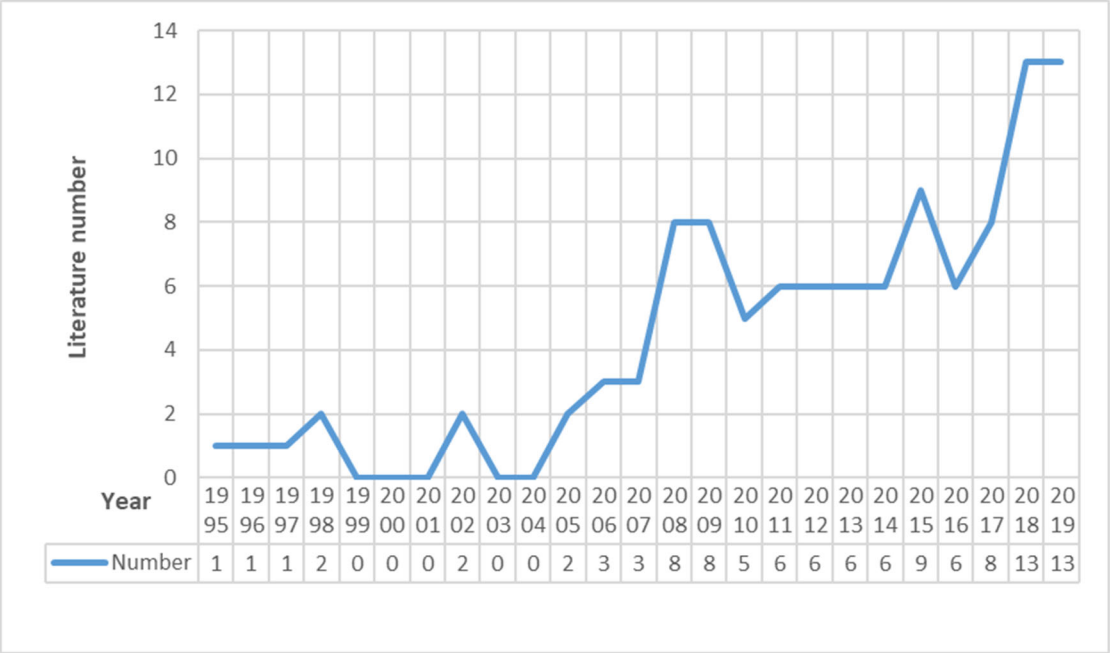

Figure 1 The annual Distribution of Deep Learning Literature

2.1.1.Dormant Period (1976-1995)

Since the birth of deep learning in 1976, deep learning has entered a long dormant period (see Figure 1). Although the literature of this period is not available in econometric statistics, we found there were still a group of scholars dedicated to deep learning research. John Biggs, professor of educational psychology, is one of the representatives. After in-depth research, they published many interesting results. The two most famous results are the SPQ Learning Process Scale and the SOLO taxonomy. The first one is to measure deep/superficial learning strategies and motivations. (Biggs, 1978), the second one is for measuring the results of deep learning (Biggs, &Collis, 1982). These two outcomes are still commonly used tools for scholars to measure the process and results of deep learning. In fact, after the 1970s, computers have gradually replaced some conventional tasks and manual tasks, and began to assist people in completing some unconventional tasks (Murane , &Levy, 1996), and promoted changes in in the enterprise's demand for talent structure: The demand for conventional skills has dropped sharply, and the demand for skills such as communication skills and expert thinking has soared (Conley, &Darling-Hammond, 2013). However, content analysis shows that deep learning at this time focuses more on the opposite of shallow learning (conventional memory, lack of deeply understanding, and just coping with exams), and it has not been in line with the above-mentioned social situation. This may be the reason why deep learning did not attract widespread attention and entered a long dormant period at this phase.

2.1.2.Germination Period (1995-2007)

Literature statistics show that in 1995, Hoon and others (1995) from Nanyang Technological University in Singapore applied deep learning strategies to high school chemistry classes for the first time to encourage students to visualize abstract concepts and explore the connections between

numerous chemical facts. Since then, deep learning research has entered a germination period, during which a small number of scholars' research and application results have appeared one after another. Content analysis shows that the concept of deep learning during this period was similar to the dormant period, still focusing on process. But in addition to exploring more ways/strategies that can promote deep learning, scholars have begun to explore formative evaluation and the support of various learning environments.

2.1.3.Emerging Period (2007-2016)

After entering the 21st century, various international organizations and countries around the world have devoted themselves to exploring what kind of new century talents should be cultivated. As a result, a variety of talent competency frameworks emerged. For example, the OECD released the DeSeCo competency framework in 2003, the European Union released the key competences for lifelong learning in 2006, and the P21 released the 21st century learning framework in 2007. Those frameworks had prompted the research of deep learning to enter the emerging stage. During this period, influenced by these key competency frameworks, an international wave of deep learning movement emerged: In 2010, the Hewlett Foundation of the United States initiated a 15-year deeper learning strategic plan (The William and Flora Hewlett Foundation, 2012). Asia Society and other ten institutions have also worked together to promote the spread of deep learning experimental schools throughout the United States (Alliance for Excellent Education, 2017). Moreover, the Victoria University in Canada launched a global deep learning initiative, cooperating with more than 1,000 schools in 10 countries to seek solutions for deep learning changes (NPDL, 2017). In 2015, the United States even issued a report to take deep learning as the national policy of education in the 21st century (National Association of State Boards of Education, 2015).

2.1.4.Rapid Period (2016 – present)

In addition to the fact that the United States regards deep learning as a national education policy, the event signaling the arrival of the rapid development period of deep learning is when the intelligent robot AlphaGo defeated the world go champion Lee Sedol in 2016. This event once increased the concern that machines would replace humans, and prompted scholars to reflect on questions such as "since humans can teach machines to learn deeply, why can't we teach children to learn deeply in school?". During this period, deep learning research has been improved in all aspects: from concept expansion, strategies testing, model construction, to mechanism exploration, evaluation development, and then to subject application. During this period, deep learning enabled by technology, especially intelligent technology, has become an emerging research trend. In particular, the release of the Core Competences for Chinese Student's Development in 2016 added a powerful fuel for deep learning research. Given this situation, Chinese Scholar Kekang He (2018) asserted that deep learning has regained the widespread attention of academia and even the general public (according to the data, the first attention occurred during the Rapid Period).

2.2.The status of deep learning research

Figure 2 shows the research status of deep learning formed by the analysis of social network centrality. The larger the box, the higher the centrality, and the distance between the boxes reflects the close relationship between keywords.

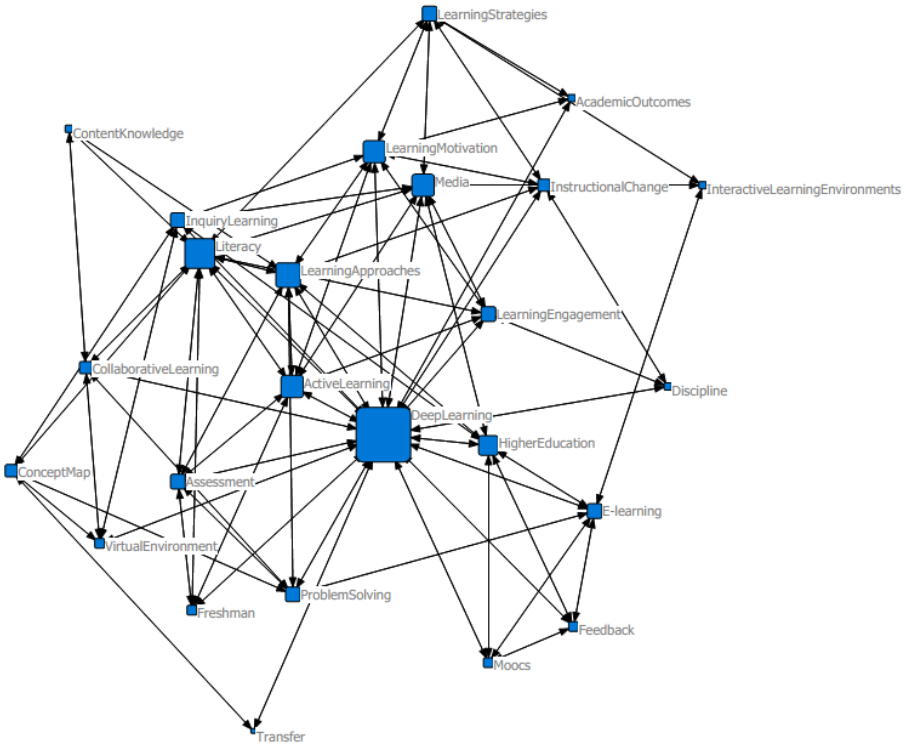

Figure 2 Community diagram of high-frequency keywords in deep learning literature

On the whole, the research of deep learning is biased towards promoting students' deep participation in learning and adopting advanced learning strategies. Specifically, In terms of deep participation learning, there is detailed research from the macro-participation culture to the micro-class participation (cognition, emotion, behavior) (Terrenghi et al., 2019; Gee et al., 2019). In terms of advanced learning strategies, scholars are committed to exploring various strategies to achieve deep learning, from peer teaching as a teacher to self-perception reflection (Nelson et al., 2014).. In terms of the development of high-level knowledge and skills, many literatures involve research on key compentencies such as creativity (Turvey, 2006) and critical thinking (Wang et al., 2015), while Figure 2 shows that it has a distant relationship with deep learning. In terms of transfer applications, there are few related studies, and the few existing mainly focus on the transfer of knowledge (Green et al., 2013; Nielsen, 2016): Figure 2 shows that transfer is on the edge of extreme remoteness confirms this conclusion.

3.The Concept Evolution of Deep Learning

At present, deep learning is more than a learning method used to understand basic knowledge, it usuallyrefers to learning strategies for obtaining advanced knowledge and its transfer.

3.1.The change of ideas

3.1.1.From pursuing understanding to pursuing transfer

In the early days, the deep learning proposed by Marton and Säljö (1976) aimed at learning approaches or strategies. Simply put, learning by understanding is deep learning, but learning by reproduction is shallow learning. Deep learning at this time is reflected at four aspects, they are

seeking meaning, connecting ideas, using evidence, and being interested in opinions. Shallow learning is mainly embodied in three aspects: information is memorized irrelevantly, learning is limited to the syllabus, and adopting minimal effort to avoid failure (Tait, & Entwistle, 1996). This kind of learning only generates a limited understanding, little connection between concepts. On this account, the famous scholar Ramsden (2003) believed that shallow learning is at best a quantity without quality (quantitative change), while deep learning is a cumulative quantity of quality (qualitative change).

It is easy to find that the goal of deep learning at this time is to understand, and the goal of shallow learning is to reproduce the test materials. Although shallow learning can produce superficial understanding, it is not one of its learning goals.

Since deep learning starts in a way of understanding and constructing meaning, people soon realized that it can lead to better transfer of knowledge and concepts (Van, &Schenk, 1984). After entering the 21st century and facing the ever-changing new situation, how to transfer what has been learned in the classroom to enable students to succeed in future work and life has become a new education challenge. Therefore, the purpose of deep learning has changed from understanding to transfer (i.e. learning for transfer), and understanding becomes the basis for deep learning to realize migration. The National Research Council of the United States has set the tone of deep learning as the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations (i.e., transfer), and the product of deep learning is transferable knowledge (National Research Council, 2012). This kind of knowledge includes not only the content knowledge of a certain field in the traditional sense, but also the knowledge of how, why, and when to apply this knowledge to answer questions and solve problems.

3.1.2.From focusing on process to focusing on outcomes

Initially, deep learning was just a kind of learning strategies that Marton and Säljö advertised for students to pursue understanding. Later, this kind of strategies were refined into the deep strategies to maximize meaning and deep motivations such as intrinsic interest in the learning process(Biggs, 1987). According to Biggs, deep strategies describe the way students are deeply involved in tasks. As a prerequisite, this kind of participation has gradually become an integral part of the deep learning process (Biggs, Kember, &Leung, 2001). In deep learning, deep participation represents the extent to which students are actively pursuing deep learning, and it refers to actively participating wholeheartedly. Today, with the emphasis on “student-centered” teaching, participation plays an increasingly important role in deep learning. Chinese scholar Yunhuo Cui (2017) even directly quoted cognitive participation to define deep learning: it is a learning that shows high involvement, high cognitive participation and gains meaning in a complex environment.

Although, after the 1970s, the demand for talents' ability has changed, that deep learning did not shift its attention from process to result until the Hewlett Foundation initiated the deep learning strategic plan in 2010. Different from the previous deep learning that focuses on the deep understanding and basic knowledge transfer, the later deep learning pays more attention to the acquisition and transfer of middle-level and high-level abilities. Correspondingly, deep learning is also known as a comparative name: deeper learning.

Through analysis of the situation at the time, the Hewlett Foundation proposed six deep learning abilities that need to be transferred and applied (The William and Flora Hewlett Foundation, 2012), they are mastering core academic content, think critically and solve complex problems, work collaboratively, communicate effectively, learn how to learn, and develop academic mindsets. Soon after, in order to explore the blend of transferable knowledge and skills and 21st century competencies, the US National Research Council identified three broad domains of competence—cognitive, intrapersonal, and interpersonal, and regarded these three competence domains as the three dimensions of deep learning knowledge and skills (National Research Council, 2012). In fact, the six deep learning abilities proposed by the Hewlett Foundation correspond to the three competence domains defined by the US National Research Council, and they both are also homogeneous with the capabilities of smart talents, as shown in Table 1.

Talble 1. The relationship between deep learning abilities, 21st century competencies and smart talents capabilities

competence domains	**six deep learning abilities proposed by the Hewlett Foundation**	**21st century competencies**	**smart talents capabilities**
cognitive	mastering core academic content	- key academic subjects -3Rs （i.e., Reading, wRiting, and aRithmetic	-master the basic knowledge proficiently
	think critically and solve complex problems (including the effective use of professional tools and techniques, as well as the ability to solve problems creatively)	- critical thinking and problem solving - computing and digital proficiency - creativity and innovation	- good at solving complex problems - good at judgment and creation
interpersonal	work collaboratively	- collaboration and leadership	- good at collaboration - make good use of technology
	communicate effectively (written, oral)	- communication and media literacy	-good at communication
intrapersonal	learn how to learn	- learning self-direction	-good at learning
	develop academic mindsets	- career, civic	- ingenuity, good personality, pragmatic

3.2. Complete solution of deep learning concepts

To sum up, the goal of deep learning has evolved from seeking understanding to pursuing transfer. It not only pays attention to the deep participation of students and the strategies students adopted in the learning process, but also pays attention to the mastery and transfer of higher-level skills. Therefore, this study summarized an elaborate definition of deep learning: Deep learning is a meaningful learning method based on understanding and pursuing transfer applications. It promotes the development of high-level knowledge and abilities by encouraging students to be deeply involved in learning and appropriate use of advanced learning strategies, then realizes the application of this knowledge and abilities in new situations or the generation of new high-level knowledge and abilities.

The definition suggests the following features of deep learning, a) deeply involved in learning, b) adopting advanced learning strategies, c) focusing on the development of high-level knowledge and abilities, and d) based on understanding and pursuing transfer are the four major characteristics of deep learning. Among them, deeply involved in learning means fully and actively participating. It focuses on student's learning involvement and the state of students' flow. Advanced learning strategy can be judged by "whether it is based on understanding" and "whether it pursues transfer application". Considering that deep learning should embody the idea of "student-centered", whether the learning strategy is advanced or not also needs to be judged "whether it reflects the initiative of the students".

High-level knowledge and abilities are as shown in Table 1. From the perspective of Bloom's taxonomy, it focuses on implementing (i.e., applying what learned in new situations), analyzing, evaluating, and creating. The understanding in d) is mostly in-depth understanding. Since reflection has been proven to be an important means of in-depth understanding (Haller, Fisher, &Gapp, 2007), this understanding can start with deep and repetitive thinking from multiple perspectives. Regarding transfer, considering that classroom teaching cannot cultivate all the knowledge and abilities to solve unknown problems in the future, this study also takes the combination or comprehensive innovation of existing knowledge and abilities as a kind of transfer. In this way, the transfer includes both the application of knowledge and abilities in new situations and the generation of new high-level knowledge.

4.The Bottleneck of Deep Learning Research

Based on our review and analysis, the existing deep learning research basically covered four major characteristics of the concept of deep learning. In addition, though the existing studies almost regard deep learning as a stable structure-oriented activity process, its flexibility issue has not received enough attention.

4.1.Deep learning demands flexibility

Whether to encourage students to be deeply involved in learning or to guide them to adopt advanced strategies, the ultimate goal of deep learning is to promote the development of students' high-order knowledge and ability and its transfer and application. Research has shown that only deep understanding can realize transfer applications, and reflection is an important means and

effective strategy to realize this understanding, what's more, some scholars even believe that reflection is the only mechanism for deep learning (Svensson, 1977). Reflection requires students to be able to review what they have learned, think repeatedly and revise existing ideas at any time. In addition, deep learning also needs students to be able to actively select suitable resources, tools, and carry out appropriate learning activities according to one's own needs. This personalization and initiative can help promote deep learning (Fullan, &Langworthy, 2014). Due to the uncertainty of the time for students to review what they have learned, the difference of review contents, and the unpredictability of their active choice of resource, tools and learning activities, the structure of deep learning activity progress should be diverse and flexible.

In the flexible progress structure, flexible and interactive self-inquiry guided by teachers is the key to the success of deep learning. Self-inquiry can make students believe that they have control over the content, methods, and time of learning, and can make them believe that their behavior is internally initiated. As a result, it leads to a greater preference for more challenging tasks and a greater willingness to put in more effort to understand (Grolnick, &Ryan, 1989), leading to deep learning. Research shows that cultivation and transfer applications of the high-level knowledge and abilities pursued by deep learning are very difficult for beginners, because they lack the schemas that experts use to solve new problems. This can easily lead to students' failure due to the lack of knowledge of self-inquiry without flexible interaction between students and teachers (Bransford, Brown, &Cocking, 2000). The failure case of deep learning of "learning while writing research papers" by Green et al. (2013) proves this point. The flexible interaction between students and teachers in self-inquiry are embodied in "individual needs, response whatever is requested, and fusion of request and its response", which is different from the teaching mode with clear distinction between student-led and teacher-led.

4.2.The challenge of flexibility

Flexibility is one of the six challenges of educational development and reform. Deep learning's demand for flexibility in the activity progress structure has touched on changes in the top-level framework structure, which further increases the difficulty of achieving flexibility.

In fact, the above flexibility is superficialn, what deep learning really needs is cognitive flexibility. This flexible feature is to organize teaching and teach knowledge in different ways, prompting students to repeatedly cross-learn (i.e., for the same content, repeated non-linear learning is carried out for many times from different perspective at different times and in different situations for different purposes). The process of repeatedly cross-learn is accompanied by the change of the context and the repetition of de-context and re-context. Context can bridge the world of knowledge and the world of life. In detail, de-context establishes a corridor from the world of life to the world of knowledge, prompting students to extract knowledge such as laws, trends, or common characteristics, and re-context establishes a corridor from the world of knowledge to the world of life: every time students solve a problem in a new situation, they will reassemble the extracted knowledge and construct the meaning of the current problem. In this way, students can form a rich and flexible understanding, and can flexibly apply or assemble relevant knowledge to solve problems in changing situations and realize transfer (Jacobson, 1996). This cognitive flexibility is a huge challenge in classroom teaching with limited time, heavy tasks and large

numbers of people.

5.Solution Measures

As to the above flexibility bottleneck, learning architecture may be an effective approach, because its outstanding feature is flexibility (MCEETYA, 2003), and it can help understand the depth of learning (Scanlan, 2013).

5.1.Towards a learning architecture

Shen (2017) provided the idea of transforming pedagogical structure into learning structure, considering the existing problems of education and combining the demands of smart learning. According to his view, learning structure advocates that students take charge of their own learning behavior, which is a unique organizational form about the presentation of learning content, organizational sequence, time allocation, self-detection and other elements formed by them with the support of specific learning space in order to achieve corresponding learning goals. In the learning structure, the main tasks of teachers are to analyze the changes of students' preferences and needs, to form diverse resources that meet their individual cognitive habits and their ways of representation and presentation, and to construct the support of various learning strategies. It is true that the learning structure fully reflects the individuality and initiative of students, and helps to promote deep learning (Fullan, &Langworthy, 2014), but it requires too high a student's learning ability and is not suitable for the basic education of primary and secondary schools. More importantly, the unique form of learning organization it represents is still concerned with the stability of teaching and learning. Therefore, this study believes that teaching needs to move towards a learning architecture, so that teaching can not only focus on the individuality and initiative of students' learning like a learning structure, but also cater to the demands of deep learning: flexibility. The relationship among pedagogical structure, learning structure, and learning architecture are shown in Figure 3.

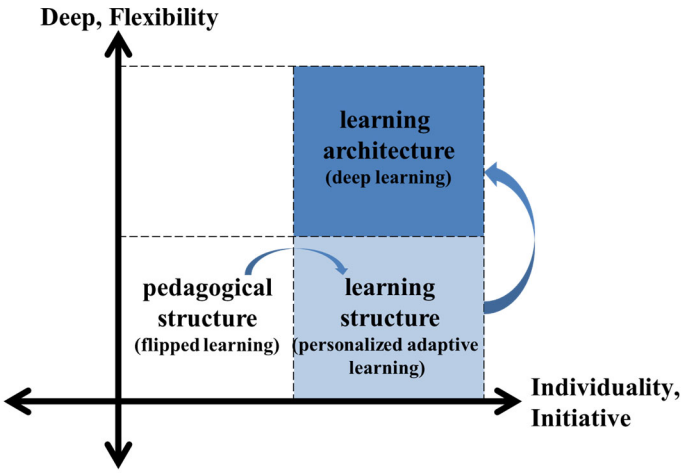

Figure 3 The relationship among teaching structure, learning structure and learning architecture

5.2. Smart classroom empowerment

Fundamentally, the shift to flexibility is driven by the development of technology. In theory, a smart classroom that integrates a variety of advanced IT technologies and media devices can empower the flexibility of deep learning. So far, although, it has not made deep learning happen as we expected.

As a paradigm of smart learning environment, smart classroom has all the functional characteristics of smart environment: seamless connection of learning space, keen perception of learning context, natural interaction of learning experience, precise adaptation of learning services, full recording of the learning process, and open and integrate of data resources (Zhu, Yu, &Riezebos, 2016). These functional characteristics give students more flexibility, effectiveness, adaptability, participation, motivation and feedback (Spector, 2014), and empower teachers and students to flexibly carry out in-depth teaching and learning. These functional characteristics give students more flexibility, effectiveness, efficiency, engagement, adaptivity,and reflectiveness (Spector, 2014), and empower teachers and students to flexibly carry out in-depth teaching and learning. Specifically, smart classrooms can flexibly create or connect context or real situations, and realize the arbitrary change of context required for cognitive flexibility;It can adaptively respond to the learning needs of students, and provide the appropriate learning support, personalized help and rich media-like learning resource ecology required for repeatedly cross-learning. Among them, the recommendation of personalized generative paths will lead to the diversity of the activity progress structure. This flexible progress can be fed back to teachers and students in real-time in a visual form.

In addition, smart classroom can pay attention to the learning status of each student, make teachers more capable of supervising, guiding and evaluating students, and feel more confident to give more initiative to students. This can also stimulate students' interest, motivation and creativity to achieve efficient and productive learning and achieve the goal of deep learning outcomes (Li, Kong, &Chen, 2015). Yu and Chen (2018) pointed out that smart classroom is a new type of classroom form that seamlessly supports deep learning with technology. However, the above research status diagram shows that the empowering role of the smart classroom has not been well explored: the smart classroom does not appear in Figure 2, and the smart learning environment as the upper concept of the smart classroom is only on the edge of extreme remoteness.

6.Conclusion

The analysis of this study shows that after more than 40 years of development, the research of deep learning has gone through dormant period, germination period, emerging period, and is now in the rapid development stage. At present, the research trend of deep learning is to promote students to be deeply involved in learning and the appropriate use of advanced learning strategies.

Two major changes of deep learning occurred in the past 40 years: a)from pursuing understanding to pursuing transfer, and b) from focusing on process to focusing on outcomes. Morover, deep learning is no longer just a learning approach to understand basic knowledge, it is more of a meaningful learning method based on understanding and pursuing transfer applications. It promotes the development of high-level knowledge and abilities by encouraging students to be

deeply involved in learning and appropriate use of advanced learning strategies, then realizes the application of this knowledge and abilities in new situations or the generation of new high-level knowledge and abilities. Among them, the generation of new higher-order knowledge and abilities is a new aspect of transfer that we advocate.

However, the analysis revealed that the flexibility of deep learning is currently overlooked, while flexibility is the appeal of deep learning. This appeal involves the change of the top-level framework structure and requires cognitive flexibility which might be extremely challenging to achieve. In this regard, this study suggests that deep learning move towards a flexible architecture and try to solve this problem with the help of the enabling of a smart classroom.

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