Construction of a Project-Based Learning Model under the Generative Artificial Intelligence Multi-Agent Collaborative Framework

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Abstract: *Generative Artificial Intelligence has achieved some results so far and will be used in project-based learning. One of the main problems in the current direction of research on educational technology is how to integrate the content generation capability of generative artificial intelligence with the distributed collaboration function of multi-agent systems organically and build an adaptive project-based learning support framework. With the progress of multi-agent collaboration in generative artificial intelligence, this paper proposes the construction of a project-based learning model and studies related problems from the aspects of theoretical foundation, architectural design and process regulation. The basis of this paper is the application logic for education of generative artificial intelligence, and architectural ideas for a multi-agent collaboration mechanism are put forward. The Design of the Learning-Support Framework at the level of architecture in this paper includes intelligent task decomposition, multi-agent role allocation and generative resource organisation. The scope of process regulation in this paper is the intelligent perception of the learning process, the appearance of features in the construction of group knowledge, and a closed-loop feedback mechanism for results. The aim of this paper is to provide a theoretical basis for the application of generative artificial intelligence in education and offer support for the intelligent transformation of project-based learning.*

Keywords: *Generative Artificial Intelligence, Multi-agent System, Project-based Learning, Learning architecture, Process regulation mechanism*

Introduction

With the development of generative artificial intelligence technology, intelligent systems based on large language models have achieved good results in language comprehension, content creation and multi-turn conversation, etc., and have opened new avenues for model innovation in education. Another kind of teaching is project-based learning; students will encounter some real-life problems and be given problems to solve in groups. The old model of project-based learning still has some problems in the division of tasks, allocation of resources, process guidance and evaluation of results. Generative artificial intelligence will be used to address the problems mentioned above, but a single model cannot meet all the different demands at different times during the process of project-based learning. Many agents have been employed to distribute and cooperate in the support of functions in a technical manner. Integration of Generative Artificial Intelligence and Multi-Agent Systems for Building a Support Framework of Features in Project-Based Learning has achieved good results in theory and practice. Generative Artificial Intelligence multi-agent collaboration will be employed to construct a general project-based learning model in this paper, and problems at the levels of theoretical foundation, architectural design and process regulation will be addressed to provide a reference for the theoretical development and technological application of project-based learning in the intelligent era.

1. Theoretical Basis and Constituent Elements of the Generative Artificial Intelligence Multi-Agent Collaborative Framework

1.1 Educational Application Logic and Technical Features of Generative Artificial Intelligence

Generative Artificial Intelligence is based on a large language model, can generate content, understand semantics, communicate over several turns, and its application in education is to reconstruct

knowledge representation methods and forms of learning interaction in depth. Generative artificial intelligence can create many kinds of text, code, diagrams, simulated scenarios, etc., based on a prompt; therefore, it is suitable for the functions of a resource generator, an idea stimulator and a thinking expander in project-based learning, and is not a traditional information retrieval system. Generative Artificial Intelligence has some good technical attributes, such as context awareness, handling of cross-modal information and emergent reasoning; it can provide flexible support for all kinds of difficult problems and be closely integrated with students' cognitive activities[1].

Generative Artificial Intelligence has some technical features and is now being used in many places to support project-based learning. Large-scale pre-training has given the model a large amount of knowledge, and then instruction fine-tuning and reinforcement learning from human feedback have been used to meet the specific needs of education. Generative artificial intelligence can create learning materials in real time and take many forms of communication, offer solutions to problems based on project-based learning tasks, etc.; thus, it is possible to change how learners obtain information and build knowledge. Another feature of the technical logic is that artificial intelligence is given the status of a subject in the learning environment, and a technical foundation has been laid for building a multi-agent collaborative framework.

1.2 Architectural Principles and Operating Rules of the Multi-Agent Collaborative Mechanism

A Multi-Agent System consists of many intelligent agents that are autonomous, have social behaviour and reactivity, and the general ideas are functional differentiation of agents and protocols for interaction. Many agents can take different forms in the educational environment; they can provide resources, observe students' learning, help with collaboration, evaluate results, etc., and together they will form a support network to cover all aspects of project-based learning by sharing information and coordinating activities. The Operating Rules for the Multi-agent Collaboration Mechanism are based on communication languages, shared ontologies and negotiation strategies; the agents operate according to these rules or learned strategies to achieve optimisation and dynamic balance of the overall goal.

Now that we have Generative AI, many more kinds of multi-agent systems have been developed that are more adaptable and capable of generation. The first kind of multi-agent system is rule-based, and with the addition of generative artificial intelligence, agents can independently change the mode of cooperation according to changes in the learning environment and generate adaptive support strategies. Cooperation among agents is no longer limited to division of labour; now they also need to understand the students' goals, foresee changes in the direction of the project, and prepare the necessary resources. The first reason for the above method is that it can combine the content generation ability of generative artificial intelligence with the distributed collaboration features of multi-agent systems to build an intelligent educational support system that is adaptable to all kinds of circumstances[2].

1.3 Reorganisation of Elements and Intelligent Transformation of the Project-Based Learning Space

The general parts of project-based learning are learning tasks, learning materials, learning activities and learning results. With the help of the Generative Artificial Intelligence Multi-Agent Collaboration Framework, some modifications and additions have been made to the above components. Learning tasks are no longer fixed presets; instead, agents will dynamically generate them and adjust the difficulty and openness of the tasks in real time according to the characteristics of the learners and the progress of the projects to keep the tasks within the learners' zone of proximal development. The organisation of learning resources will be changed from a fixed set of resources to an on-demand generation model, and generative artificial intelligence will instantly create context-appropriate learning materials according to the needs of projects to improve the matching efficiency of resources and tasks.

Intelligent Transformation of the Project-Based Learning Area has been realised in the construction of interaction relationships and outcome forms. The form of interaction in learning activities has changed from a simple kind of person-to-person contact to a complex network of people and machines, multi-agents, etc.; now, agents act as intermediaries and regulators for learners and tasks to promote deep development in group knowledge construction. The presentation of learning results has moved away from the traditional forms of texts and works to become a collection of all sorts of results now, such as process data, generated content and reflections. The result set shows what has been learned, and it is also related to how it has been learned. Not only has new technology been added, but by altering the relationships among the learning elements, a new kind of learning environment that is adaptive,

generative and cooperative has also been created.

2. Design of the Project-Based Learning Architecture Based on Multi-Agent Collaboration

2.1 Intelligent Decomposition and Dynamic Adaptation Mechanism for Learning Tasks

Intelligent Decomposition of Learning Tasks creates artificial intelligence to obtain the semantics and structure of the project goal. A multi-agent system will successively break down the general goal of the project into a hierarchy of sub-tasks according to the theme of the project, the cognitive level of the learners and the intrinsic logical relationship among the tasks. Task decomposition is not the division of a process into small parts; rather, by considering the interdependence of tasks, the necessary resources and the degree of difficulty, an interconnected network of tasks will be constructed in the system. Generative artificial intelligence can be used to generate task representations and optimise the decomposition path of tasks; at the same time, it is also possible to change the granularity and complexity of tasks according to changes in the project environment[3].

The main link in the dynamic adaptation mechanism is the problem of matching students with tasks in time. Continuously collect data on students' interactions, progress and cognitive abilities by the multi-agent system to build a characteristic model of the students, and then, based on this model, adjust the difficulty of the tasks, the type of tasks and how they are presented. If a student cannot solve a small part of the problem independently, the adaptation mechanism can break down that part further or offer some help. If the student can solve the problem easily, increase the difficulty level of the next one automatically. Therefore, the learning tasks will always be at the top end of what the learners can do independently, and there will be a suitable level of challenge for them.

2.2 Multi-Agent Role Assignment and Cooperative Interaction Mode

The division of labour for some agents will be in line with the demands and goals of different times in project-based learning. According to the division of functions, the four kinds of agents are task-guiding agents, resource-providing agents, process-monitoring agents and reflection-promoting agents. The task-guiding agent will organise the progress of the project and prompt for task completion. According to the demand, the resource-providing agency will publish some learning materials or recommend them. The Process-Monitoring Agent will observe the learning behaviour and then issue a warning. The agent of promoting reflection helps students know themselves better through questions and talk. All kinds of agents have different functions and are connected by information to form a support network for all aspects of project-based learning.

The Construction of the collaborative interaction mode is based on the communication protocols and negotiation mechanisms of agents. At the start of the project, the agents will work together to collect information on the aims of the project and the learners. At the stage of project progress, agents learn independently according to their own functions and communicate and cooperate with each other at important links. There are conflicts among the agents and competition for resources; thus, they negotiate to reach an agreement on behaviour. Generative artificial intelligence can be used to have agents interact more freely and not be restricted by their existing knowledge; based on changes in their environment, they can generate suitable interaction content and cooperation modes in an aware manner to form a collaborative mode.

2.3 Generative Organisation and Adaptive Flow Path of Learning Resources

Changes in the content, form and order of the materials can be regarded as modifications to the production organisation of learning materials. Generative artificial intelligence can create teaching materials according to the current needs of learning, adapt to all stages of project tasks, consider the cognitive characteristics of students, and solve any problems in the interaction process. The forms of the resources are diverse, and there are many types, such as text, diagrams, code snippets, simulated scenarios, dialogues, and so on. The organisation of the resource sequence is based on the cognitive laws of progression from concrete to abstract and from simple to complex, and individual modifications are made according to the cognitive style and learning needs of the students to create an adaptive resource supply path.

Based on the actual demand and supply of resources in different areas of the construction site, a new flow path will be established. The direction of the flow of resources is determined by the extent of

task demand, the cognitive state of the learner and the degree of resource matching. If a student does not understand the content of a problem in a particular exercise, a help module will immediately show explanatory notes or tutorials. If there are any knowledge gaps among the students, then resources will be distributed and shared among them. The Path of Flow is not fixed; rather, it will be built dynamically according to how much the learners participate in the project and what tasks need to be completed. Generative artificial intelligence can dynamically change the content and form of teaching materials according to feedback obtained during the course of teaching, and these teaching materials can be integrated with learning activities[4].

3. Process Regulation Mechanism of Learning under the Generative Multi-Agent Collaborative Framework

3.1 Intelligent Perception of the Learning Process and Collaborative Intervention Strategies

Intelligent Perception of the Learning Process is based on the collection and analysis of all kinds of learning data in real time. Continuously collect interaction paths, dialogue content, task completion status and cognitive representation products of learners from the perception nodes in the project-based learning environment via a multi-agent system and build a multi-dimensional representation of the learning process. Generative AI will be used to conduct semantic understanding and pattern recognition in this way to extract important information from the unstructured learning dialogue, determine the cognitive state, emotions and collaboration level of the learner, build a contextual model based on the above information, and spread it among the agents. As individual learners have different behaviours, various forms of group cooperation have been used, and different results have been obtained; thus, a perception mechanism has been established to construct a multi-level representation of this process at both the micro and macro levels[5].

According to the situation model obtained by intelligent perception and the preset regulation rules, construction of the collaborative intervention strategy is carried out. If the system finds that the direction of learning is out of line with the norm or there is a cognitive block, the corresponding functional agents will take corrective actions in accordance with the negotiation mechanism. At all levels of intervention, at the individual level, it includes giving hints, helping to solve problems, providing resources, etc., and at the group level, it covers cooperation restructuring, task adjustment and discussion direction. Generative artificial intelligence can modify the content of interventions according to all sorts of circumstances and create personalised feedback based on how learners express themselves and think in various ways. The intervention behaviour of all agents works together to achieve the goal; there is no redundancy or conflict in the interventions of these agents, and the regulatory activities are in harmony and effective.

3.2 Emergent Characteristics and Evolutionary Laws of Group Knowledge Construction

With the development of generative multi-agent collaboration, the construction of group knowledge has also changed. As a mediator, the multi-agent system will collect all the opinions, conversations, results, etc., that occur during the group's work, organise and integrate this scattered knowledge in an organised way using generative artificial intelligence, help externalise tacit knowledge, and coordinate all the various views. In the collaborative session of project-based learning, students' talk, resources, ideas, etc., provide the basis for knowledge construction. According to the above materials and semantic analysis, recognise and organise associations to build a knowledge network at the group level in a multi-agent system. The process of emergence is not only the accumulation of knowledge but also the organisation and generation of knowledge elements by agents to form new knowledge structures that are superior to what can be achieved through individual cognition.

To find the laws of evolution, we need to observe how the knowledge network of the group has changed over time. At the start of the project, the group's knowledge construction is in the form of various opinions and different resources; therefore, a multi-agent system will be used to organise the initial integration of knowledge elements via topic clustering and association recommendation. At the stage of project progress, a knowledge network has been constructed, some basic concepts and key problems have started to emerge, and at this time, agents take the lead in in-depth knowledge construction by leading discussions and providing argumentative support. At the end of the project, the group will organise the knowledge it has gained into transferable results, and the agents will help learners develop metacognition by observing their learning progress and providing feedback. At the

same time, generative artificial intelligence has also been continuously adding links among the nodes of knowledge to keep the group knowledge network dynamic and capable of generation during its development[6].

3.3 Various Expressions of Learning Outcomes and Feedback Loops

All kinds of learning outcomes do not have to take the same form; they can be organised in an integrated way, combining process-oriented products with result-oriented products. According to the framework of generative multi-agent collaboration, the learning results include not only the final works or reports produced for the project but also all the various intermediate products generated during the course of the project, such as problem definition documents, solution sketches, discussion minutes, reflection logs, and learning trajectory data recorded by the multi-agent system. Generative AI will organise and present the process-oriented materials to give the students a general overview of their studies. There are many ways to present the results, such as written words, graphs and charts, spoken dialogue, animations, etc.; according to how they are used and what the audience needs to learn, all kinds of presentation methods can be chosen flexibly.

At the base of the feedback loop mechanism is a cycle of learning results and the process of learning. The Multi-Agent System will analyse and evaluate the results of learning, then provide all sorts of feedback to learners, teacher groups and the agents themselves. Feedback for learners generally covers the quality of their results, the development of their abilities and improvement directions, and it takes the form of generative comments, comparisons, suggestions, etc. The teacher group has pointed out problems in the Design and Support of the project. Feedback will be given to the agents to improve the perception model, intervention strategy and resource organisation of the agents. The multi-agent system will spread the feedback information to all nodes in the learning process, change the decomposition of the next task, modify the distribution of resources and cooperation among agents, and so on, to form a closed-loop optimisation mechanism for learning and achieving results. Continue to use the above method for the optimisation of the model of project-based learning and improve both the efficiency of learning and the performance of the system.

Conclusion

Based on the Generative Artificial Intelligence Multi-agent Collaboration Framework, a project-based learning model is proposed in this paper, and then this model will be introduced in more detail regarding its theoretical basis, architectural design and process regulation. In this paper, we introduce the theoretical basis of Logic for Educational Applications and the technical features of generative artificial intelligence, present the architectural Design and operating rules of the multi-agent collaboration mechanism, and also show the element restructuring and intelligent transformation features of the project-based learning space under technological intervention. Based on the above research, at the level of architectural Design, a project-based learning support framework has been set up to distribute tasks, assign roles, organise resources, etc., and thus a system Design scheme with dynamic adaptability and collaboration can be achieved. At the level of process regulation, this paper studies intelligent perception and collaborative intervention strategies in the learning process, the emergent characteristics and evolutionary laws of group knowledge construction, various representations of learning outcomes, the feedback loop mechanism, etc., to find the regulatory path and optimisation logic of the learning process under intelligent support. The foundation of this paper will be used to provide some background information on the application of generative AI in education. Further research can study the adaptation and adjustment modes of all kinds of educational environments in light of this framework, deepen the understanding of the emergence laws in the process of multi-agent collaboration, and promote the theoretical integration and technological development of generative artificial intelligence and project-based learning.

References

[1] Guo, Q., et al. "On How Generative Artificial Intelligence Empowers Teaching from a Disciplinary Perspective: Taking Scientific Project-Based Learning as an Example." China Educational Technology, no. 01 (2026): 75-83.

[2] Liu, Y., and Jiang, D. Y. "Integrating Technology and Culture: Exploration of Chemistry Project-Based Learning Empowered by Generative Artificial Intelligence." Digital Teaching in

Primary and Secondary Schools, no. 01 (2026): 71-75.
[3] Su, R. "The Logic, Path and Reflection of Generative Artificial Intelligence Empowering Interdisciplinary Project-Based Learning." Theory and Practice of Education, vol. 45, no. 32 (2025): 3-7.
[4] Gao, L., and Zhong, J. Y. "Practical Exploration of Project-Based Learning Empowered by Generative Artificial Intelligence Based on Dialogic Learning." China Information Technology Education, no. 13 (2025): 88-92.
[5] Zhang, W. Y. An Empirical Study on Generative Artificial Intelligence Promoting Project-Based Learning in Blended Classrooms. MA thesis, Sichuan Normal University, 2025.
[6] Dong, J. Y. "Exploration of the Path of Generative Artificial Intelligence Empowering Interdisciplinary Project-Based Learning." Basic Education Curriculum, no. 02 (2025): 22-29.