Construction of a Trinity Teaching System Based on "Computational Thinking + Artificial Intelligence + X"

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Abstract: *With the spread of artificial intelligence technology in all parts of society, one of the current problems in education is how to integrate computational thinking, artificial intelligence methods and subject-specific knowledge effectively in teaching. First, it will determine the necessary attributes of computational thinking and how to integrate them in cross-curricular teaching; second, it will clarify the rational basis for introducing artificial intelligence technology into the teaching system; finally, it will establish the compatibility among the X-domain knowledge representation and the other two parts to build a trinity teaching system based on "Computational Thinking + Artificial Intelligence + X". Based on the above, the dimensions of competency have been set up in the system, ternary mapping relationships among knowledge units have been established, integrated teaching content has been organised according to task chains, and system elasticity and extensible interfaces have been added for dynamic adaptation. Further analyze the constraints on the co-evolution of the three elements during teaching, set regulation parameters and optimisation directions for cognitive load, put forward a system self-updating ability and cross-cycle effectiveness evaluation framework. Organise the teaching materials of all subjects in an organised and scalable way according to this system.*

Keywords: *Computational Thinking, Artificial Intelligence, Teaching System, Ternary Mapping, Task Chain, Cognitive Load Regulation*

Introduction

With the rapid development of computational thinking and artificial intelligence technology, the way knowledge is organised and skills are taught in many fields has changed recently. However, there is still no systematic construction method at the level of the teaching system for the organic integration of the formal logic of computational thinking, data-driven methods of artificial intelligence and domain-specific knowledge in a particular field (X-domain). The current work only adds or lists the three parts sequentially; therefore, there is no knowledge point semantics and the cognitive load is too heavy. Therefore, we need to build a teaching system that can cultivate the ability of abstract modelling, algorithmic thinking and domain adaptation at the same time. The first goal of this paper is to provide a general construction framework that is not bound by any specific technology, and to put forward some design rules for the division of competency factors, arrangement of knowledge modules, organisation of task chains and operational control. Build a ternary mapping relationship and an elastic expansion mechanism in the system, adjust it according to changes in the X-domain, continuously improve the artificial intelligence technology to keep up with cross-cycle efficiency.

1. Foundations for the Integration of Computational Thinking, Artificial Intelligence and the X-Domain

1.1 General Features of Computational Thinking and Its Applications in Various Fields

The first type of computational thinking is to break down a large problem into several small and simple steps, and the four characteristics are abstraction, decomposition, pattern recognition and algorithm design. Abstraction is to extract the necessary information in a particular situation and ignore the rest; decomposition is to break down a large problem into several small, simple ones; pattern recognition is to find common characteristics among various problems; and algorithm design is to create a specific way to solve problems under certain or uncertain circumstances. With the development of interdisciplinary studies, computational thinking is no longer limited to computer science; now it has become a general way to describe problems and solve them that has been applied in all areas of knowledge creation and dissemination. Computational thinking is used in the teaching system for "Artificial Intelligence + X" to connect abstract logic with problems in a particular field; that is to say, an official way is provided to organise artificial intelligence methods with concepts from the X-domain. Therefore, computational thinking is not only a way of thinking but can also be used as an analysis system for metacognition to organise differences in meaning and levels of operation among various knowledge systems[1].

1.2 The Technical Elements of Artificial Intelligence and the Logical Starting Point for Embedding Them in the Teaching System

The first few general components of artificial intelligence are representations of data, learning algorithms, inference and decision-making, etc. Data representation refers to feature extraction, vectorisation and embedding representation; learning algorithms are in the form of supervised, unsupervised and reinforcement learning; inference and decision-making cover probabilistic graphical models, logical inference and output interpretation of deep networks. At the beginning of adding them to the teaching system, we need to determine which AI functions have the basic attribute of cross-domain transferability. General classification and regression do not need domain knowledge; clustering and dimensionality reduction can find structure in the data, and sequential decision-making has an adaptive mechanism, so these are stable modules that should be given high priority for embedding in the teaching system. The embedding method is reversible in terms of mapping from the problem definition to algorithm selection; that is, given a problem statement in the X-domain, one can reverse-engineer to find the corresponding AI technical elements and their positions in the framework of computational thinking. The above logical starting point will keep the foundation for teaching stable and avoid having to frequently change the structure of the content due to rapid changes in technology.

1.3 Alignment of X-Domain Knowledge Representation with Computational Thinking and Artificial Intelligence

The X-domain is any professional field with its own system of knowledge, and generally speaking, the methods for representing knowledge are symbolic rules, empirical discriminative criteria and quantitative models. To promote good coordination with computational thinking and artificial intelligence, formalisation should be carried out on the native knowledge of the X-domain. The three levels of the alignment method are as follows: First, there is entity and attribute mapping; that is, objects, attributes and relationships in the X-domain are converted into computable data structures such as tensors, graph structures or symbol tables. The second level is the mapping of processes and algorithms; that is to say, the operating workflow in the X-domain is divided into steps of computational thinking, and then each step is mapped to a specific part of artificial intelligence algorithms. Third, there is a unification of evaluation indicators; that is to say, the performance indicators in the X-domain (such as error tolerance, response time and resource utilisation) are converted into loss functions or constraint terms for machine learning. Coordination is not only the use of technology but also a kind of two-way semantic adaptation; computational thinking offers a way to organise decomposition, artificial intelligence is used to carry out data-driven inference, and the X-domain provides the problem context and validation basis. The three parties had different degrees of participation in the alignment and finally formed a joint operation model for teaching content[2].

2. Structured Construction Path of the Trinity Teaching System

2.1 Decomposition of Competency Dimensions and Ternary Mapping Relationships of Knowledge Units

Decomposition of competency dimensions is to divide a student's general abilities into several basic parts according to the stages of cognition. The three kinds of attributes in the Trinity System are: Abstract Modelling Ability (derived from computational thinking), Algorithm-Driven Capability (derived from artificial intelligence), and Domain Adaptation Capacity (derived from the X-domain). Abstract Modelling ability is the same as the category and process abstraction category of knowledge units; algorithm-driven capability corresponds to the data representation category and model optimisation category; and domain adaptation capacity is in line with the semantic mapping category and constraint expression category. According to the correspondence rules of these competency dimensions with the knowledge units, ternary mapping relationships are established, and the rule is that each knowledge unit should belong to the intersection area of at least two competency dimensions to avoid system fragmentation caused by the single-attribute nature of knowledge units.

The actual construction of the mapping relationship is an association matrix. Row vectors are knowledge units, column vectors are competency dimensions, and the elements of the matrix take values from {0, 1, 2}; 0 indicates no direct association, 1 indicates a supportive association, and 2 indicates a core association. If a knowledge unit has two or three main associations with the same dimensions, it is called a hub node in the system. The dynamic adjustment mechanism of the ternary mapping relationship can change the weights of the competency dimensions during operation; for instance, when there are changes in the data characteristics of the X-domain, the weight of domain adaptation ability will increase, and the corresponding knowledge units will be switched from supportive associations to core associations. An association-matrix-based mapping method can be used to organise the teaching content and other materials in an orderly manner.

2.2 Organizational Strategy for Integrated Teaching Content Based on Task Chains

A task chain is a set of tasks that have progressiveness and interdependence, and all these tasks have operational requirements in the three dimensions of computational thinking, artificial intelligence and the X-domain. The Design Principle of task chains is that the output of one task serves as the direct input for the next task, and thus there is a dual inheritance relationship for data flow and control flow. The three stages of a typical task chain are as follows: The first kind of task is to clean the raw data and organise it in the X-domain, and at this time, decomposition decisions are made based on computational thinking. The second kind of problem is how to organise the training data and optimise the parameters of artificial intelligence models; that is to say, how to build an algorithm. Finally, the third type of task is to obtain understandable conclusions in the X-domain from the output of the model, and for this purpose, domain adaptation ability and abstract modelling skills are employed together. The length and branch structure of the task chain can be set according to the required level of granularity for the system; short chains are suitable for verifying a single skill, and long chains can cover all the content in a chapter.

The organisation of the integrated teaching content should be based on the coverage relationships of task chains and knowledge units, not on one-to-one correspondence. Task chains generally have several knowledge units, and a single knowledge unit can be used in many different task chains; therefore, there is a many-to-many relationship among them, and teaching materials will be more reusable and flexible. Change the recursion depth or loop nesting level of computational thinking to modify the gradient of difficulty for task chains, and also change the interpretability requirements of artificial intelligence models and the number of prerequisite dependencies in the X-domain knowledge. The boundary conditions of a task chain are the input specifications at the head of the chain and the output acceptance criteria at the tail of the chain; together, they provide a basis for determining whether the task chain has been completed. The organisation above is not too mechanical or rigid; rather, it links the knowledge points of the three dimensions along the path of task execution[3].

2.3 System Elasticity and Extensible Interface Design for Dynamic Adaptation

The Elasticity of the teaching system is its capacity to be stable and, at the same time, introduce new knowledge and technology. There are two types of Elastic Design: vertical elasticity is to adjust the granularity of the competency dimension; that is, each competency dimension can be further divided into sub-dimensions without changing the basic structure of ternary mapping, and horizontal elasticity refers to the replaceability of the X-domain, which means that when switching from one professional direction to another in the X-domain, only the domain-specific knowledge units and the mapping matrix need to be updated, and the core skeleton of computational thinking and artificial intelligence remains unchanged. The two indices of elasticity are the cost of system restructuring (the proportion of knowledge units that need to be changed) and the speed of system convergence (the change in sparsity of the mapping matrix after adding new knowledge)[4].

An extension interface has been added to support the addition of third-party content modules, and there are three kinds of standard interfaces. The first is the standard data interface, and it should be possible to convert the data in the X-domain into a general tensor form. Second, there should be a standard algorithm interface; that is to say, all the integrated artificial intelligence components need to provide a unified call protocol and specify the dimensions of input and output, as well as the range of hyperparameters. The third is the knowledge unit registration standard; that is to say, the new knowledge unit needs to declare the corresponding values in the competency dimensions in the form of an association matrix. The interface is loosely coupled; that is to say, the integrated modules and the system kernel only need to know about the standard protocols mentioned above and do not need to know the specific implementation details. An extension interface has been added to handle version control, and the same interface can now support the co-existence of content modules from different versions and meet the demand for content replacement due to technological changes smoothly.

3. System Operation Mechanism and Effectiveness Regulation Model

3.1 Analysis of Constraints on the Co-evolution of the Three Elements During the Teaching Process

Co-evolution of the three elements refers to the fact that computational thinking, artificial intelligence and the X-domain are constantly affecting and changing each other in many ways at all levels of teaching representation. The two kinds of constraints are internal constraints and external constraints. The first is related to the operation range of the three dimensions themselves: algorithmic expressions of computational thinking require that the problems be discretisable; given the data-driven nature of artificial intelligence, a sufficient number of labelled examples or definable reward signals must exist; and the knowledge integrity of the X-domain should not be damaged by oversimplification of key semantics. The three kinds of internal divisions are not overlapping. For example, the very abstract symbolic knowledge in the X-domain cannot be used directly as training data for artificial intelligence, so computational thinking needs to be employed to construct a surrogate task and generate an approximate data distribution. Generally speaking, the identification of internal constraints can be done by looking at the entries with a value of 0 in the association matrix of knowledge units; these zero-association positions indicate links that are difficult to couple naturally among the three elements.

External constraints are the time and resource limitations of the operation of the teaching system. Time is a limited resource; therefore, the total number of cognitive operations that learners can process in a single teaching period is finite, and thus the number of iterations and the extent of feedback in the co-evolution of the three elements are also limited. The requirements for computing power and data storage in the various X-domains are quite different, so based on the available resources, artificial intelligence models and different levels of abstraction in computational thinking should be chosen according to the system. All the above conditions determine the range of combined operation for the three parts in the system. When the constraint boundary moves, the original coordination state will be disturbed, so we need to change the weights of the competency dimensions to maintain stability[5].

3.2 Regulation Parameters and Optimisation Directions for Cognitive Load

Cognitive load here refers to the total amount of cognitive resources that need to be employed simultaneously by learners in the process of processing the formal logic of computational thinking, the algorithmic procedures of artificial intelligence and the domain knowledge of the X-domain. The three kinds of regulation parameters are as follows: For the dimension of computational thinking, the two regulating factors are the number of abstraction levels (the range from concrete cases to general patterns) and the granularity of decomposition (how many subtasks each task is divided into). The two control parameters of the AI part are the degree of interpretability of the model (e.g., end-to-end black boxes vs. fully transparent decision trees) and the number of degrees of freedom for hyperparameter tuning. The Regulation Parameters for the X-dimension are the density of domain terminology (the number of new concepts per unit of teaching content) and the path length of prerequisite knowledge dependencies. The range of these parameters is[0, 1], and they have been normalised for ease of weight and comparison.

The Goal of the optimisation direction is to keep the total cognitive load index low and ensure that the main knowledge units of the ternary mapping are covered properly. Gradient descent is used to optimise the parameters in the optimisation process, but it is not necessary for the function to be differentiable; instead, one can discretely change the level of each parameter and observe the quality feedback obtained from learners after completing the task chain. A good direction for the regulation is to reduce the recursion depth of computational thinking rather than to decrease the number of abstraction levels, as the latter is more likely to harm the semantic integrity of the X-domain. For the artificial intelligence part, it is better to reduce the degrees of freedom of hyperparameters than to reduce model interpretability, as the latter would weaken the verifiable link with knowledge in the X-domain. According to the increase in the complexity of the intermediate representations generated during the execution of task chains, the regulation parameter is changed dynamically; if this increase exceeds a certain limit, then the corresponding dimension of the parameter is reduced.

3.3 System Self-Updating Ability and Cross-cycle Effectiveness Evaluation Framework

A characteristic of self-update in a teaching system is that it can change its own structure and parameter settings according to operating data and do so independently. The Self-Update Mechanism is based on version control for the knowledge unit association matrix. At the end of each teaching round, collect data on how often each block of knowledge is used, how long a chain of tasks takes to be completed, and any other observations of cognitive load, and then update the weight of the association matrix for the next round based on this data. Based on the two principles above, new weak associations will be added for knowledge units that have an implicit connection to other knowledge units and frequently show zero association but are actually frequently used by learners (changing the value from 0 to 1); knowledge units that have not been triggered for a long time and do not have strong associations with other units will be marked as eligible for dormancy and moved to an alternative repository instead of being deleted directly. There is a manual review period for the self-update process, but the review function does not change the automatically generated weight recommendations; it only records the modifications for the threshold calibration stage later[6].

According to the framework of cross-cycle effectiveness evaluation, it will be determined whether the system has maintained the coverage and synergy efficiency of the original design goals after several rounds of teaching. The three dimensions of the evaluation indicators are: the computational thinking dimension is the change in skewness of the distribution of abstraction levels; the artificial intelligence dimension is the shift in repeated patterns of model component invocation sequences; and the X-dimension is the drift of forgetting curve parameters for domain knowledge units. A sliding window is used to evaluate the cross-cycle; the mean and variance of the stability coefficients in a group of three cycles are calculated, and if the variance exceeds the upper and lower tolerance limits, then a structural review of the system will be carried out. The threshold for effectiveness has been set so that if the proportion of core associations in the association matrix is less than 15 per cent of the original value, then a rollback mechanism will be triggered to return the system to the previous stable state. There are no outside reference data; only the operating data of the system itself will be used to obtain the evaluation results.

Conclusion

The framework Design of the "Computational Thinking + Artificial Intelligence + X" trinity teaching system in this paper has been completed at the three levels of integration foundation, structured construction path and operation mechanism, as well as a regulation model. To solve the problem of semantic alignment among the three dimensions, these competency dimensions have been further divided, ternary mapping has been applied to knowledge units, integrated teaching content has been organised in progressive task chains, and elastic structures and extensible interfaces have been added to allow for dynamic adaptation. At the level of operation, the constraints of co-evolution are specified, regulation parameters and optimisation directions for cognitive load are proposed, a version-based self-updating mechanism for the association matrix is built, and a cross-cycle effectiveness evaluation framework is established. In the future, many cases in the X-domain of concrete content will be studied to verify the convergence behaviour of the association matrix, adaptive learning algorithms that regulate the parameters of cognitive load will be developed, and through cross-cycle evaluation, the quantitative relationship between stability coefficients and system architecture will be examined. Extend the high-dimensional extension of the ternary map to cover several X-domains at once and explore this option further.

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