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2025 Volume 3, Issue 6
Lecture Notes in Education, Arts, Management and Social Science
ISSN(Online): 2705-053X

Construction of Hierarchical Classification Graphs for Scientific Models from the Perspective of SOLO Classification Theory

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Abstract: As an important tool in scientific research and teaching, the level of construction and understanding of scientific models directly reflects the scientific cognitive ability of learners. Based on the SOLO classification theory, this paper constructs a hierarchical classification diagram of scientific models from the two dimensions of knowledge structure and thinking complexity, dividing the cognitive level of scientific models into five levels: pre-structure, single structure, multiple structure, associative structure, and abstract extension structure, and analyzing the characteristics of each level in combination with specific disciplinary cases. The study shows that this classification map can provide precise tools for science education evaluation, facilitate the implementation of personalized teaching, and provide theoretical support for the digital transformation of science model teaching in the era of artificial intelligence.

Keywords: SOLO Classification Theory; Scientific model; Hierarchical classification diagram construction

Online publication: July 26, 2025

1. Introduction

A model is an abstract and approximate representation of a natural process, phenomenon, or system, and it is the foundation of scientific exploration and the exchange of scientific ideas. From elementary school's "goldfish movement model", "pine growth model" to junior high school's "cell structure model", "atomic structure model" to senior high school's "ecological energy flow model", "Earth rotation model", models have always accompanied science education. SOLO classification theory is a theory oriented to the structure of learning outcomes that presents a new perspective, namely, a hierarchical classification model based on the cognition of scientific models of SOLO theory. Compared with the hierarchical differences based on cognitive behavior, SOLO classification pays more attention to the structural differences in the organization of knowledge by learners, and these structural differences are the criteria for differentiating learners' cognitive levels and depth. In today's era when intelligent education models have become a trend in the field of education, constructing a hierarchical classification map of scientific models based on SOLO theory with the help of intelligent education can provide an operational framework for intelligent diagnosis of students' scientific knowledge level, thereby providing an important theoretical basis for science education supported by artificial intelligence.

2. The core essence of the SOLO classification theory and its compatibility with the scientific model

2.1. The hierarchical framework of SOLO classification theory

The SOLO classification divides learning outcomes into five progressive levels, each of which shows significant differences in the characteristics of the thinking structure.

Pre-structured level: Learners' understanding of knowledge is in a state of confusion and they are unable to establish effective associations between information and tasks. For example, when analyzing a population growth model, one can only randomly list terms such as "birth rate" and "death rate", but cannot explain their relationship to the model curve [1].

Single structural hierarchy: Focusing only on one relevant information in the task and ignoring the relevance of knowledge, that is, when understanding the photosynthesis model, only remembering "sunlight is needed" and forgetting chloroplasts, carbon dioxide, etc.

Multistructural hierarchy: Being able to identify multiple relevant information but failing to integrate them into a coherent system. For example, when describing a "chemical equilibrium model", the effects of temperature and concentration can be explained separately, but the synergistic mechanism of these factors cannot be explained.

Associative structure hierarchy: It can organize unorganized knowledge fragments together to form an organic whole, creating a relatively complete knowledge structure. As in the discussion of the "Plate tectonics model", activities such as earthquakes, volcanoes, and continental drift can be linked together.

Abstract expansion of the structural hierarchy: It can be abstracted and innovatively applied beyond the given information to form new cognitive perspectives. Such as proposing new personalized medical solutions based on "gene expression models", or predicting the evolution trends of extreme weather through "climate models".

2.2. The intrinsic fit between SOLO theory and the scientific model

The cognitive process of the scientific model is essentially a process of structuring knowledge and complicating thinking, which is highly consistent with the core proposition of the SOLO theory:

Structure-oriented matching: The construction of a scientific model needs to go through an advanced process of "element identification - relationship sorting - system integration - innovative expansion", which is consistent with the hierarchical leap of SOLO from a single structure to an abstract extended structure [2].

The order of thought complexity: from the physical model of the scientific concept (such as the model of the DNA double helix) to the mathematical formula of the scientific concept (such as Newton's laws), the complexity of the representation of the scientific concept also goes from low to high, which aligns with the order of thought complexity at the SOLO level [3].

Dynamic and associative correspondence: The learner's understanding and grasp of the scientific model is not stored knowledge, but rather a process of progressive development with the enrichment of cognitive structure, which corresponds to the "dynamics of learning outcomes" of the SOLO theory.

3. The value of constructing hierarchical classification graphs of scientific models from the perspective of SOLO classification theory

First, provide precise assessment tools for the cognitive level of scientific models. The core of the SOLO classification lies in focusing on the structure of learning outcomes, and the hierarchical classification graph of scientific models inherits this feature, which can clearly distinguish the cognitive levels of learners towards scientific models. Traditional evaluations often remain at the surface level, such as judging whether the model drawing is correct, but this classification diagram can delve into the two-dimensional structural level, from confusing understanding of the pre-structural level, isolated element memory of the single structural level, to systematic integration of the associated structural level, innovative application of the abstract extended structural level, just as the SOLO classification can accurately assess the true cognitive level of learners, To avoid being misled by the ability to acquire information on the surface, this classification map can accurately diagnose the true level of cognition of scientific models.

Second, provide clear guidance for the implementation of personalized teaching. The SOLO taxonomy takes into account individual differences among learners, and so does the hierarchical classification diagram of the scientific model. Teachers can develop targeted teaching strategies based on the hierarchical positioning of learners in the classification map. For students at a single structural level, more explanations of the basic elements of the model and simple exercises can be pushed; For students who have reached the associative structure level, comprehensive case studies and extended research topics are provided to meet the cognitive development needs of different learners, like the SOLO taxonomy guiding individualized learning paths and promoting teaching to be more in line with students' actual situations.

Third, provide an effective path for developing higher-order thinking skills. The SOLO classification emphasizes the cultivation of thinking abilities such as knowledge integration and innovation, and the scientific model hierarchy classification map is also oriented towards this. It guides learners from lower-level element memorization to higher-level knowledge integration and innovative application. Under the requirements of the associative structure and abstract extension structure levels, learners need to integrate knowledge from different fields to form new insights, enhance the ability to distinguish and analyze information, cultivate innovative thinking and comprehensive application ability that adapt to the times, and contribute to the all-round development of scientific literacy [4].

4. Construction Framework of the Hierarchical Classification Diagram of the scientific Model

Based on the five-level structure of the SOLO theory and in combination with the constituent elements of the scientific model (representation form, element association, application scenario, innovation expansion), construct the hierarchical classification diagram of the scientific model as follows:

4.1. Pre-structural level: The chaotic period of model cognition

Characterization: Inability to extract the main concepts of the model, partial and deviated understanding of the model, such as analogizing the "atomic model" to a simple model of "the earth revolving around the sun", ignoring quantum nature.

Thinking performance: When faced with model-related questions, only random associations or irrelevant responses can be made, and an effective connection between information and tasks cannot be established.

Typical behavior: When drawing a "blood circulation model", randomly connect blood vessels to organs and fail to distinguish the functional differences between arteries and veins.

4.2. Single structural level: The period of element recognition in model cognition

Representational features: Capturing a single feature of the model while ignoring the relationships between the elements of things. For example, when understanding the "ecological pyramid model", it captures "producers at the bottom" but fails to notice the issue of transmission efficiency.

Logical reasoning: Able to make logical inferences based on a single variable, not applicable to multi-variable reasoning. For example, in the explanation of the reason for the "pendulum model", it is only assumed that the period of the pendulum is related to the length of the pendulum, not to the amplitude, and not to the acceleration due to gravity [5].

Typical behavior: When using the "chemical equation model", only the number of atoms can be balanced, but the influence of reaction conditions on the product cannot be analyzed [6].

4.3. Multiple structural levels: The element correlation period of model cognition

Feature representation: Capable of identifying certain elements and partial relationships in the model, with a low degree of connection between the elements. For example, when describing the "S-curve model of population growth", the role of environmental capacity and initial quantity can be stated, but the dynamic relationship between the two cannot be explained.

Thinking performance: Capable of independent analysis of multiple elements, but lacking systematic integration ability, the reasoning process shows the characteristics of "distributed points".

Typical behavior: When interpreting the "weather system model", they can describe the changing patterns of air pressure and humidity separately, but are unable to comprehensively judge the evolution trend of the weather system.

4.4. Associative structure level: The system integration period of model cognition

Representational level: Able to incorporate the components of the model into a unified whole and know the complete effect produced when the elements of the model are interconnected. For example, in characterizing the "cellular respiration model", one can link glycolysis, the citric acid cycle, and the electron transport chain to illustrate all the pathways of energy release [7].

Mental performance: Possessing systems thinking ability, capable of multi-element collaborative reasoning to form a structured cognitive framework.

Typical behavior: When applying the Lenz Law model, one can accurately determine the direction of the induced current by integrating information such as the direction of the magnetic field and the state of motion of the conductor.

4.5. Abstract expansion of structural levels: A period of innovative transcendence in model cognition

Characterization: The ability to go beyond the established form of the model, conduct abstract generalization and innovative application, construct new model variants or expand the applicable fields of the model. Such as analyzing ecological competition strategies based on a "game theory model", or simulating the learning process of the brain through a "neural network model".

Thinking performance: Possessing abstract logic and innovative thinking, capable of transferring models to new situations and presenting breakthrough insights.

Typical behavior: When studying "epidemic spread models", optimize model parameters in combination with big data technology to improve prediction accuracy, or propose targeted prevention and control strategy models.

5. Construction Method of Hierarchical Classification Graph for Scientific Models from the perspective of SOLO Classification Theory

First, build a hierarchical skeleton based on the five-level framework of the SOLO classification. The SOLO classification system divides learning outcomes into five levels: pre-structure, single structure, multi-structure, associative structure, and abstract extension structure. The construction of the scientific model hierarchical classification diagram should be based on this core framework. Each level corresponds to a specific stage of the scientific model cognition. For example, the pre-structure level corresponds to the learner's confused understanding of the model and inability to identify the core elements; a single structural level corresponds to being able to identify individual key elements of the model but ignoring correlations; multistructural hierarchies can identify multiple elements but lack integration; associative hierarchical correspondence can integrate elements into a system; abstract extended hierarchical correspondence can innovate the application of models. This hierarchical division directly draws on the SOLO taxonomy's focus on the structure of learning outcomes, ensuring consistency between the classification graph and the theoretical origin [8].

Second, refine the hierarchical elements of each level division. According to the different judgments of the level of knowledge integration and the complexity of thinking based on the SOLO classification theory, the classification diagram needs to clearly present the element characteristics of each level in terms of the way the scientific model is expressed, the structural relationship, the application scope, etc. For example, at the single-structure level, it is required to describe whether the learner can identify a certain element in the model (such as the types of atoms contained in the chemical equation in a reaction), and at the multi-structure level, it is required to reflect the learner's "individual" identification of multiple elements (such as reaction conditions, states of the reacting substances), At the link structure level, it is required to show the "interrelationships" of different elements (such as how the reaction conditions affect the product). The advantage of doing so is that it reflects both the emphasis of SOLO theory on the structure of thought and the cognitive characteristics of the scientific model.

Third, establish a verification process based on the requirements of the background for the use of the SOLO classification method. The SOLO classification is effective in open test evaluation and complex task diagnosis. The construction of the classification diagram should be based on this, and the division of each level should be verified through teaching practice to see if it meets the requirements of the usage context [9]. For example, the relevant explanations of different models (such as force analysis models, ecosystem models) in different educational stages and student cases of problem-solving can be matched with the requirements of each level of the classification diagram. If the representation of the characteristics of a certain level does not cover this performance of the student, the definition of the elements of that level needs to be modified. So that the classification map can accurately diagnose the cognitive level of the model in the context of use, just as the SOLO classification method can accurately diagnose the learning level of students in teaching assessment [10].

Fourth, refine the classification logic based on individual differences among students. SOLO classification emphasizes individual differences in the organization of knowledge among learners, and the construction of classification diagrams should also reflect this awareness. At each level of description, there should be room for atypical manifestations resulting from possible differences in knowledge bases and ways of thinking among different learners. For example, at multiple structural levels, some learners may be more concerned with the mathematical representation of the model, while others are more concerned with the textual representation of the model. The classification diagram should recognize this difference and divide the levels mainly based on “the lack of integration of multi-element recognition”, avoiding artificial over-solidification and maintaining the inclusiveness of the classification logic.

6. Conclusions

The hierarchical classification diagram of scientific models from the perspective of SOLO classification theory breaks through the superficial limitations of traditional model evaluation and provides a precise cognitive diagnostic tool for science education by depicting the hierarchical differences in knowledge structure and thinking complexity. The practical value of this classification map is reflected in three aspects: at the level of teaching evaluation, it realizes the transformation from “result judgment” to “process diagnosis”; at the teaching design level, it promotes the transformation from “unified teaching” to “personalized guidance”; at the technology application level, it supports the upgrade from “simple interaction” to “intelligent adaptation”. In the context of the deep integration of artificial intelligence and education, the hierarchical classification diagram of scientific models will provide strong support for cultivating students’ higher-order thinking abilities and promoting the all-round development of scientific literacy.

Disclosure statement

The author declares no conflict of interest.

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