ISSN 2508-2817 KiDRS Korea Institute of Design Research Society 통권 36호, 2025. Vol.10, No.3

A Theoretical Framework for User Mental Models in Learning Analytics Systems

학습 분석 시스템 사용자 정신 모델의 이론적 프레임워크 연구

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https://doi.org/10.46248/kidrs.2025.3.9

접수일 2025. 08. 20. / 심사완료일 2025. 09. 01. / 게재확정일 2025. 09. 08. / 게재일 2025. 09. 30.
본 논문은 2020학년 대한민국 교육부와 한국연구재단의 지원을 받아 수행된 연구임 (NRF-2020S1A5C2A04092451).

Abstract

Learning analytics systems are increasingly being utilized in teaching and learning environments to support data-driven feedback provision and learning outcome improvement. However, the effectiveness of these systems depends not only on analytical accuracy but also on how users perceive and utilize the provided information. Existing research has pointed out that the diversity in learners' ways of perceiving and utilizing systems can lead to misalignment between system functionality and user expectations. Nevertheless, systematic research on how learners construct mental models of learning analytics systems and how these can be utilized for user-centered design remains insufficient. This study aims to explore the user mental models formed during the process of using the TPIS system and to propose a framework that can systematically analyze and construct them. The proposed framework classifies cognitive elements that appear in user-system interactions and provides a theoretical foundation for systematizing mental model research in the context of learning analytics systems. Through a case study of the TPIS system, this study derived a conceptual framework that classifies users' mental models in learning analytics systems along two axes: Individual-Universal and Observable-Unobservable. Based on this framework, four mental model types (Operational, Situational, Strategic, and Interpretive) are presented to explain various aspects of user-system interaction. The proposed framework explains user cognitive processes in the TPIS system context while simultaneously providing a practical foundation for reflecting user experience in future learning analytics system design and improvement processes. Through this, the present study expands the discussion on mental models in learning analytics system research and presents the possibility of developing user-centered design strategies.

Keyword

Learning Analytics System(학습 분석 시스템), Mental Model(정신 모델), User Experience(사용자 경험), User-System Interaction(사용자-시스템 상호작용)

요약

학습 분석 시스템은 교수·학습 환경에서 데이터 기반 피드백 제공과 학습 성과 향상을 지원하기 위해 점점 더 활용되고 있다. 그러나 이러한 시스템의 효과는 단순한 분석 정확성에만 의존하는 것이 아니라, 사용자가 제공된 정보를 어떻게 인지하고 활용하느냐에도 달려 있다. 기존 연구는 학습자가 시스템을 인지하고 활용하는 방식의 다양성이 시스템 기능과 사용자 기대 간의 불일치를 초래할 수 있음을 지적해 왔다. 그럼에도 불구하고 학습자가 학습 분석 시스템의 정신 모델을 어떻게 구성하는지, 그리고 이를 사용자 중심 설계에 어떻게 활용할 수 있는지에 대한 체계적 연구는 여전히 부족하다. 본 연구는 TPIS 시스템을 사용하는 과정에서 형성되는 사용자 정신 모델을 탐색하고, 이를 체계적으로 분석 및 구축할 수 있는 프레임워크를 제안하는 것을 목적으로 한다. 제안된 프레임워크는 사용자-시스템 상호작용에서 나타나는 인지적 요소를 분류하고, 이를 통해 학습 분석 시스템 맥락에서 정신 모델 연구를 체계화할 수 있는 이론적 토대를 제공한다. TPIS 시스템 사례를 통해 학습 분석 시스템에서 사용자의 정신 모델을 개인-보편과 관찰 가능-관찰 불가능의 두 축으로 분류하는 개념적 프레임워크를 도출하였으며, 이를 기반으로 사용자-시스템 상호작용의 다양한 측면을 설명하는 네 가지 정신 모델 유형(운영형, 상황형, 전략형, 해석형)을 제시하였다. 제안된 프레임워크는 TPIS 시스템 맥락에서 사용자 인지 과정을 설명하는 동시에, 향후 학습 분석 시스템의 설계와 개선 과정에서 사용자 경험을 반영할 수 있는 실질적 기반을 제공한다. 이를 통해 본 연구는 학습 분석 시스템 연구에서 정신 모델에 관한 논의를 확장하고, 사용자 중심 설계 전략으로 발전시킬 수 있는 가능성을 제시한다.

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1. Introduction

1-1. Research Background

Learning analytics has emerged as a technological approach that diagnoses learning processes and provides corresponding feedback based on learners' behavioral data in digital educational environments.[1] Particularly in teaching-learning contexts where interaction is fundamental, such as collaborative learning or project-based learning, the importance of learning analytics systems that quantitatively assess team members' contributions, communication, and engagement levels while providing real-time analysis has been emphasized. Developed in response to these needs, the TPIS system aims to provide various multimodal data collected in team-based learning situations and support data-driven feedback for both learners and facilitators. The TPIS system offers advanced learning analytics tools, including speech content analysis, gaze-tracking analysis, team communication summary reports, and real-time feedback functions. However, learning analytics systems with complex features can increase cognitive load and lead to misapplication and misinterpretation due to discrepancies between intended use and actual user behavior. According to user analysis results, learners and facilitators often experience difficulties in interpreting the information or feedback provided by the system, and additionally, they face significant challenges in learning how to use its intended functions effectively. Numerous cases have been identified where users only partially utilize the system's core functions or make inaccurate decisions due to a misunderstanding of analysis results. Also, many instances have been observed where users

1) Siem, R., Learning Analytics: Drivers, Developments and Challenges. International Journal of Technology Enhanced Learning, 4(5-6), 2012, pp.304-317.

interpret visualized indicators in a fragmented manner or use the system inefficiently due to a misunderstanding of the information provided. This phenomenon addressed discrepancies between the initial intentions of the system and the users' perceptions, leading to a concept closely related to the "users' mental models."

Mental models are concepts that explain how users internally represent and understand the structure and functions of external environments or systems. They have been extensively recognized as foundational theories in the fields of Human-Computer Interaction (HCI) and User Experience (UX) design. Particularly for systems with complex information structures, system usability and user experience can vary significantly depending on how well user mental models align with actual system models and designer models. Nevertheless, theoretical frameworks that structurally explain user mental models in the context of learning analytics systems remain limited in the existing literature. Most previous research has focused on usability evaluation or system function analysis, with relatively insufficient structural analysis of how users perceive, interpret, and incorporate these systems into their behavioral patterns.

1-2. Research Objective

A learning analytics system is a tool designed to facilitate learning by collecting, processing, and analyzing data to enhance learning processes and outcomes. However, the effectiveness of the system extends beyond merely disseminating data, but relies heavily on comprehending users' cognitive processes in interpreting information. Previous studies indicate that users interpret information provided by learning analytics systems at different levels, and outcomes can vary based on individual cognitive frameworks, learning backgrounds, and familiarity with technology.[2] In particular, cognitive challenges when using the system, along with complex and ambiguous information, and the difficulty in interpreting visualization and feedback data, can cause confusion among users. This confusion may result in inefficient use of the system and a lack of trust in the analysis outcomes. These problems ultimately suggest that fundamental solutions are difficult without analyzing how users perceive and understand the system's structure and functions—specifically, the nature of the mental models they construct. Nevertheless, existing learning analytics research has predominantly emphasized functional efficiency and learning outcomes, while theoretical frameworks addressing user mental models and their integration into system design remain underdeveloped. Therefore, this study aims to explore the mental models that users form during the process of using the TPIS system and propose a framework that enables the systematic analysis and construction of these models. The proposed framework classifies cognitive elements that emerge in user-system interactions and provides a theoretical foundation for systematizing mental model research within the context of learning analytics systems.

This study addresses the following research questions:

RQ1. What are the fundamental components that constitute the mental models of TPIS system users?

RQ2. How does the proposed framework relate to actual system architecture and user cognitive processes and behavioral patterns?

2) Dollinger, M., Lodge, J. M., & Coates, H., Co-Creation in Learning Analytics: Recognising and Reflecting on the Complexity of the Learning Environment. Australasian Journal of Educational Technology, 35(4), 2019, pp.1–14.

2. Theoretical Background

2-1. Mental Models

2-1-1. Conceptual Definition of Mental Models

Mental models are defined as conceptual structures that represent reality, enabling individuals to understand particular phenomena more effectively. Norman's (1983) main contribution describes them as follows: "In interacting with the environment, with others, and with the artifacts of technology, people form internal, mental models of themselves and of the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction."[3] The theoretical basis of mental models originates from Craik (1943), who proposed that individuals comprehend the world and its mechanisms through internal mental representations.[4] According to Craik's framework, individuals continuously access and modify these internal representations—known as mental models—in their continuous cognitive processes to draw conclusions and predict outcomes. Mental models are detailed cognitive frameworks that depict physical systems, accurately reflecting users' understanding of the system's components, operations, and underlying reasons for its functionality.[5] From a cognitive science perspective, Johnson-Laird (1983) described mental models as internal representations that enable individuals to understand and reason about the world, serving as mental frameworks for prediction and explanation. He highlighted their "central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life."[6] Building upon this foundation, Norman (1983, 1986) developed the theoretical framework of mental models as cognitive schemas that help users to understand system features and anticipate outcomes. Norman (1988) also defined mental models as users' conceptual understanding of system operation, emphasizing their role in predicting user behavior and shaping design principles. Young (2008) expanded the concept of mental models from a user research perspective to encompass users' expectations, assumptions, and knowledge structures that they develop and utilize during task execution and decision-making.

2-1-2. Fundamental Characteristics of Mental Models

According to Norman (1983), mental models exhibit six primary characteristics that shape how users interact with and understand systems. First, mental models are inherently incomplete. Second, individuals possess a limited capacity to execute or apply their mental models effectively. Third, mental models demonstrate instability, with users frequently forgetting system details over temporal intervals. Fourth, the boundaries of mental models are often indistinct, resulting in confusion between similar devices and operations. Fifth, mental models may incorporate unscientific or superstitious behaviors that are maintained to minimize cognitive effort. Sixth, mental models are parsimonious, as users tend to favor additional physical actions over complex mental planning, thereby optimizing for simplicity and reducing potential confusion. These characteristics indicate that users' mental models do not align with the actual system architectures; instead, they develop dynamically based on individuals' experiences, knowledge, and contexts.

3) Gentner, D., & Stevens, A., Mental Models. Hillsdale, NJ: Erlbaum, 1983.

4) Craik, K., The Nature of Explanation, 1943.

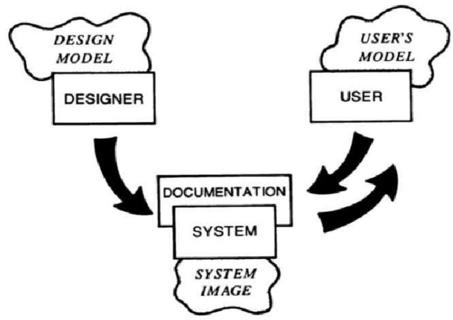
5) Carroll, J. M., & Olson, J. R., Mental Models in Human-Computer Interaction: Research Issues About What the User of Software Knows. National Academy Press, 1987, p.12.

6) Johnson-Laird, P., Mental Models. Cambridge, MA: Harvard University Press, 1983, p.397.

2-2. Disciplinary Perspectives on Mental Models

2-2-1. Mental Models in the Context of UX Design

Norman (1983) identified three related but separate concepts in system design: “First, there is the conceptualization of the system held by the designer; second, there is the conceptual model constructed by the user; and third, there is the physical image of the system from which the users develop their conceptual models.”[7] He highlights these three ideas to clarify how users develop their understanding of interactive systems. The *Design Model* refers to the system conceptualization created by the designer, representing its main principles and logic. The *User's Model* is the mental image that develops through users’ interactions, which may differ from the designer's original conceptualization. The *System Image* encompasses the system’s visible elements, including its interface, documentation, and instructions, that influence users’ perceptions of the system. As shown in Figure 1,[8] these distinctions highlight the potential gap between design intentions and user perceptions, where discrepancies may occur between designers’ conceptual goals and the mental models that users develop. The figure illustrates how the design model is translated into the system image and how users subsequently construct their own models based on it.



[Figure 1] Norman’s (1986) mental model.

Young (2008) established a new paradigm that diverged from conventional system-centered mental model methodologies by emphasizing the actual behaviors and cognitive processes of users. Young's mental model theory comprises the following fundamental principles: First, goal-oriented cognitive structures. Users’ mental models are not limited to specific products or interfaces but are formed around the goals and motivations that users aim to achieve. Second, it involves the systematic application of qualitative data science methodologies. Young introduced a structured approach that explores users’ actual cognitive processes through in-depth interviews, observational research, and qualitative analysis. This method focuses on understanding users’ intrinsic motivations and the contexts that are difficult to capture exclusively with quantitative data. Third, the systematic discovery of opportunity spaces. The ultimate goal of mental model research is to identify unmet user needs and find opportunities for developing new products or services.

Specifically, Norman’s approach focuses on adapting systems to users’ mental models, while Young's approach emphasizes thoroughly exploring users' mental models to identify new design opportunities. In mental model-based design, the core principle is not to communicate how a system actually works, but rather to organize and present information in a way that users can easily understand. Various elements, including visual, interactive, informational, and

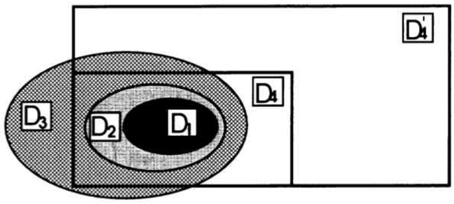
7) Norman, D. A., Cognitive Engineering. In D. A. Norman and S. W. Draper (Eds.) User Centered System Design, 1986, p.47.

8) Ibid., p.46.

feedback components and functions, significantly affect usability and interpretability depending on how well they align with users' existing cognitive frameworks.[9)]

2-2-2. Mental Models in Human-Computer Interaction

In the context of HCI, user models are often conceptualized through the alignment and misalignment between users' mental representations and the actual system functionality.



[Figure 2] Mental model derived from Human-Computer Interaction (HCI)

As shown in Figure 2,[10)] the ovals represent the user's understanding of the system's conceptual set, while the rectangle (D4) displays the functionalities provided by the system. The innermost area, D1, refers to concepts that are well internalized, frequently used, and easily accessible during users' routine interactions. Surrounding this, D2 represents concepts that are only vaguely understood and occasionally used, often requiring external support such as passive help systems. D3, on the other hand, indicates concepts that users assume exist within the system, reflecting their expectations or assumptions about its design. Finally, D4 includes the actual functionalities available in the system. Notably, the region encompassing D3 and D4 highlights a critical source of usability issues: concepts that users expect the system to support but are missing. These gaps reveal differences between the user's mental model and the designer's system model, often leading to confusion, inefficiency, or frustration.

2-2-3. User Cognition and Mental Models in Learning Analytics Systems

Learning analytics systems serve as tools to evaluate learners' states through behavioral data and foster self-regulated learning with visual feedback.[11)] However, their effectiveness depends not only on providing data but also on how users interpret and respond to that information. According to Dollinger et al. (2019), learners often interpret dashboard visualizations not through a straightforward and intuitive understanding, but rather based on prior experiences or biased expectations. This often leads to misinterpretations or misuse of system features. Similarly, Matcha et al. (2020) found that users of learning analytics dashboards have highly varied perceptions, resulting in different interpretations of the same data and the adoption of diverse learning strategies. These findings suggest that the mental models users create have a greater impact on learning outcomes and user satisfaction than the system's utility or accuracy. Nevertheless, current research often treats mental models only as fragmented user responses or interpretive differences. In contrast, a structured framework that systematically explains mental models and integrates them into system design remains limited.

9) Belkin, J., Anomalous States of Knowledge as a Basis for Information Retrieval. Canadian Journal of Information Science, 5(1), 1980, pp.133-143.

10) Fischer, G., User Modeling in Human-Computer Interaction, User Modeling and User-Adapted Interaction (UMUAI), 11(1), 2001, p.72.

11) Dawson, S., Gasevic, D., Siemens, G., & Joksimovic, S., Current State and Future Trends: A Citation Network Analysis of the Learning Analytics Field. In Proceedings of the Fourth International Conference on Learning Analytics and Knowledge, ACM, 2014, pp.231-240.

3. Learning Analytics Systems

3-1. Overview of the TPIS System

The TPIS is a learning analytics system designed to monitor learners' processes in real-time and collect and analyze various data types such as learning logs and task performance records. This system provides facilitators with indicators to diagnose overall engagement patterns and learning outcomes of learner groups, while also offering learners customized feedback and information to support personalized learning. Notably, the TPIS system enables the analysis of complex learning behaviors using multimodal data, including gaze tracking, voice analysis, and facial expression recognition, representing a significant improvement over existing systems that depend on single-modal data. The system's feedback analyzes multimodal data to provide personalized diagnostics on individual and team learning. It accurately measures learners' states, which fosters engagement and improves outcomes.

3-2. Analysis of User Behavior Characteristics

The behavior of users within the TPIS system can be broadly delineated into three stages: (1) data interpretation, (2) feedback processing, and (3) learning strategy modification. Although empirical data from the TPIS system were not utilized in this study, the behavioral traits examined are derived from existing literature in learning analytics, user experience, human-computer interaction, and self-regulated learning. During the data interpretation stage, learners attempt to understand their current learning status through visualized information and analytical indicators. However, prior research has repeatedly demonstrated that inconsistencies between users' mental models and the system's intended representations can lead to cognitive overload and interpretation errors.[12)13)] For instance, when the TPIS system calculates online class participation based on activity logs, some learners may interpret this simply as 'participation scores increase merely by attending lectures until the end.' However, if system designers intended to reflect substantive interaction and contribution levels, learners may engage in behaviors that undermine the system's intended purpose. Furthermore, learners respond differently to feedback based on their individual expectations and prior experiences. Research on feedback in self-regulated learning indicates that learners decide to accept or reject feedback based on their perception of its usefulness and credibility.[14)] This suggest that the feedback may be differentially interpreted across learners, thereby influencing engagement and subsequent actions. In the learning strategy adjustment stage, some learners adjust their study strategies based on insights from the system, whereas others maintain habitual approaches. Self-regulated learning literature highlights that strategy adaptation is contingent on learners' metacognitive awareness and reflective capacity.[15)] Consequently, TPIS system may influence not only learners' immediate actions but also the gradual formation and refinement of their mental models regarding effective learning strategies. By situating these stages within established research, this analysis underscores that the design should prioritize understanding how users interpret and engage with the system rather than merely expanding functional capabilities. In particular, strategies aimed at reducing discrepancies between learners' mental models and the system's representations are

12) Norman, D. A., The Design of Everyday Things. Basic Books, 1983.

13) Nielsen, J., Usability Engineering. Academic Press, 1993.

14) Shute, V. J., Focus on Formative Feedback, Review of Educational Research, 78(1), 2008, pp.153–189.

15) Winne, P. H., & Hadwin, A. F., Studying as Self-Regulated Learning. In D. H. Schunk & J. A. Greene (Eds.), Handbook of Self-Regulation of Learning and Performance, 2008, pp.277–304.

directly linked to improved user experience and enhanced learning outcomes.

4. The TPIS System Mental Model Framework

4-1. Limitations of Existing Classification Systems

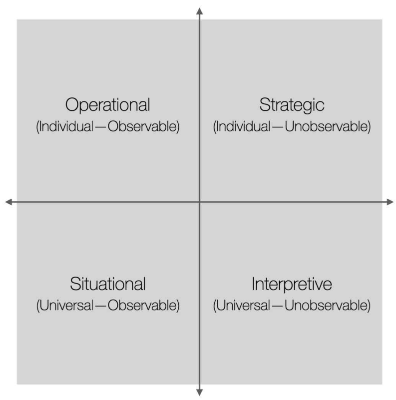
Existing mental model classification systems mainly use single-dimensional frameworks, limiting their ability to represent the complex, multidimensional nature of mental models. These limitations arise from neglecting their intricate nature and the diversity of cognitive and contextual traits among users. The distinction between structural models and functional models proposed by Norman (1988) has been widely accepted as one of the foundational classification systems in mental model research. Structural models describe system components, while functional models focus on tasks and processes. This binary view is limited as it neglects users' characteristics, experience, expertise, or specific scenarios.

Rouse and Morris (1986) proposed a classification system that differentiates between individual models and shared models, highlighting the social aspect of mental models. Individual models are based on personal experiences and learning, while shared models are created within groups and cultures, emphasizing social interaction and group learning in the formation of mental models. This classification, however, overlooks differences in models' abstraction, concreteness, and cognitive complexity. Gentner and Stevens (1983) presented another dimension of classification systems by distinguishing between mental models, concrete models, and abstract models from the perspective of cognitive complexity. Concrete models highlight observable features like physical elements users can see and manipulate, while abstract models emphasize conceptual frameworks, principles, rules, and relationships. However, they fail to differentiate between individual characteristics and universal attributes and overlook interactions.

Existing classification systems rely on a single criterion, failing to capture the multidimensional nature of mental models. They also fail to sufficiently reflect the dynamic and contextual characteristics of mental models and have limitations in assessing differences in users' cognitive stages and domain expertise. Users' mental models are complex, interconnected structures involving structural, functional, individual, social, concrete, and abstract aspects. Consequently, new classification systems should account for these diverse dimensions.

4-2. Mental Model Types in TPIS System Context

As shown in Figure 3, the classification framework produces four types of mental models representing different aspects of user interaction with the TPIS system. Each quadrant represents the four types of mental models—Operational, Strategic, Situational, and Interpretive—that serve as tools to analyze cognitive and behavioral patterns during user-system interactions.



[Figure 3] A Mental Model Framework for the TPIS System

4-2-1. Two-Dimensional Classification System of Mental Models

(1) Dimension A: Individual ↔ Universal

The first dimension distinguishes between the specificity and universality of mental models. Individual emphasizes unique characteristics that depend on specific users or contexts. This refers to concrete and personalized mental models shaped by personal experiences, learning preferences, or intuitive ways of understanding. For instance, if a learner interprets a particular dashboard indicator as "a measure of how diligently I am completing assignments," this reflects an individual model grounded in personal experience.

In contrast, Universal refers to generalized patterns that commonly appear among multiple users. These models transcend individual contexts and encompass socially constructed cognitive structures or typical patterns of understanding, as well as behavioral and cognitive trends repeatedly observed in group-level data. For instance, if learners consistently demonstrate low comprehension of a specific learning material across a course, this represents a universal model that can be used to understand collective tendencies of the learner group. Thus, universal models provide a crucial foundation for identifying cognitive and behavioral patterns shared at the group level, extending beyond individual differences to inform system design. Ultimately, this dimension serves as a criterion for determining whether learners' mental models in the TPIS system are grounded in individual specificity or collective universality.

(2) Dimension B: Observable ↔ Unobservable

The second dimension represents the level of concreteness of mental models. Observable focuses on elements that are visible and measurable. This includes substantial and visible components, such as physical actions like button clicks, menu navigation, and interface touchpoints, as well as concrete outputs like learning log data. For instance, the understanding users form by manipulating functional buttons, examining data visualization charts, or interpreting feedback messages in the TPIS system represents a typical observable mental model. Such models can be immediately traced in the course of user interaction and are directly applicable to analyzing patterns of learning behavior.

Unobservable refers to mental models at abstract and internal levels, including emotions, attitudes, motivations, and values. Learners interpret feedback in various ways beyond performance data, including emotional support to reduce anxiety or motivation to persist, or as a reflection of values like self-improvement and responsibility. They may also view the TPIS system as a tool that fosters an engaging learning environment and long-term achievement. This dimension ultimately provides criteria for distinguishing whether user mental models are formed based on observable behaviors or constructed through abstract cognitive and emotional interpretations.

4-2-2. TPIS System Mental Model Types and Applications

The two mental model classification system proposed in this study provides a framework for systematically explaining and predicting the experiences of TPIS users. In particular, the two dimensions of personal-universal and physical-abstract play an important role in connecting the learning data that TPIS system collects, analyzes, visualizes, and prescribes with users' cognitive activities. The four mental model types derived accordingly can be specifically applied in the TPIS system context as follows.

(1) Operational Mental Models: Operational mental models are defined as the mental frameworks formed when particular user groups interact with concrete interfaces or functions. In the context of the TPIS system, usability mental models primarily correspond to understanding the information structure and recognizing

functions. Learners need to intuitively identify the location of specific indicators on the dashboard and which buttons to press to achieve the desired results. When this model is clearly established, users can reduce the unnecessary burden of exploration and efficiently utilize learning data.

(2) Situational Mental Models: Situational mental models are defined as universal behavioral patterns that appear in general activities or situations, regardless of specific brands or products. These models are closely connected to role concepts and learning behaviors that learners universally possess, even in situations where the TPIS system is not being used. In the context of the TPIS system, learners using the system do not simply remain as individual users; they simultaneously perform roles within social contexts, such as 'learne', 'team member', or 'evaluation subject'. The data collected by the TPIS system reflects the contextual behavioral patterns of learner groups, transcending individual system experiences. This becomes an essential foundation that learning analytics algorithms must be able to interpret. System usage extends beyond utilizing specific functions and becomes linked with universal interaction patterns within the learning community, including learning habits, participation methods, and collaboration patterns that learners already possess. Therefore, the TPIS system's design should incorporate these contextual behavioral patterns to align with the users' current universal behavioral frameworks.

(3) Strategic Mental Models: Strategic mental models are defined as mental frameworks related to the decision-making processes of user groups with common goals or values. In the TPIS environment, these models are associated with the process by which learners interpret system data and select personalized learning strategies. For instance, judgments such as "my participation has been low this week, so I need to contribute more to discussions" or "my concentration time has decreased, so I need to change my learning patterns" reflect conceptual decision-making models formed based on the feedback. This extends beyond data verification, relating to learners' goal setting, self-regulation, and learning direction. These mental models help learners convert raw analytics into actionable insights, bridging data presentation and meaningful behavioral change in their learning journey.

(4) Interpretive Mental Models: Interpretive mental models are defined as universal cognitive structures and cognitive biases held by general user categories. In the TPIS system, these models refer to the universal cognitive structures and biases that learners use to interpret data and feedback. Typical cognitive biases include phenomena where learners accept that "low scores mean I am failing" when viewing specific data, or excessively interpret causal relationships, such as "since concentration indicators are good, overall achievement will also be high." These universal cognitive patterns influence how users interpret learning analytics data across various individual contexts. Therefore, the TPIS system should provide visualization and guidance strategies that consider users' general cognitive structures during the data interpretation process, helping to mitigate potential misinterpretations arising from common cognitive biases.

5. Conclusion

This study proposes a user mental model framework for understanding the learning behaviors, user cognition, and system usage processes of TPIS system users. The proposed framework is structured around four dimensions of users, with each dimension aiming to comprehensively describe the cognitive, emotional, and behavioral patterns that users may experience when interacting with the system. The proposed framework provides a theoretical foundation that designers can utilize to gain a more accurate understanding of learners internal thought structures and behaviors, and to design customized feedback provision, interface improvements, and learning analytics systems based on this understanding. Future research should collect application cases across various learning environments and user groups, and verify the framework's practicality and predictive power through sophisticated analysis linked to multimodal learning data. In conclusion, this study presents the possibility of user-centered approaches and mental model-based design strategies in learning analytics system design, suggesting that it can provide fundamental theoretical and practical contributions to the development of learning analytics systems similar to the TPIS system.

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