

Exploration and Practice of the Application of Eye-Tracking Technology in University Mathematics Teaching

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Abstract: As a tool for quantifying individuals' visual attention and information processing, eye-tracking technology is gradually being applied in the reform of higher education. This paper focuses on issues in university mathematics teaching, such as heavy cognitive load, delayed feedback, and insufficient adaptability. Based on theories of cognitive psychology, the study explores application pathways of this technology in cognitive diagnosis, instructional optimization, classroom regulation, personalized support, and teaching assessment. Research shows that eye-tracking data can reveal key cognitive features during the learning process, enhance the visualization of instructional feedback, and improve the scientific basis of decision-making. This provides both theoretical support and practical reference for data-driven and precise transformation in university mathematics education.

Keywords: Eye tracking; University mathematics; Teaching reform; Data driven

Online publication: Oct 21, 2025

1. Introduction

University mathematics, as a core component of the foundational curriculum in higher education, plays a critical and unique role in cultivating students' logical thinking, abstract reasoning, and mathematical modeling competence. However, for a long time, the teaching of this course has commonly faced practical challenges such as abstract content, delayed feedback, and learning difficulties. The traditional lecture-based teaching model emphasizes knowledge transmission while neglecting cognitive processes. Students often lack timely feedback and effective support during learning, resulting in difficulties understanding, keeping up with, and mastering the material, factors that significantly impact teaching quality and learning outcomes.

With the rapid advancement of educational information technologies, an increasing number of researchers have begun to explore the potential of these technologies in instructional reform ^[1]. Eye-tracking technology, which can record individuals' visual attention behavior in real time, has recently gained growing attention in

the field of education ^[2,3]. This technology captures key data such as learners' gaze positions, fixation durations, and visual scan paths during learning, uncovering their cognitive processes in receiving, processing, and understanding information. Compared to traditional methods like tests and questionnaires, eye-tracking data offers greater objectivity, real-time insights, and visual representation, opening new avenues for identifying learning difficulties and optimizing instructional feedback ^[4].

At present, eye-tracking technology has shown promising applications in areas such as language learning, science experiments, and programming education. However, its use in university mathematics education is still at an early stage, with related practices remaining fragmented and lacking systematic exploration. Therefore, this study focuses on university mathematics courses and attempts to integrate eye-tracking technology into teaching reform. By targeting key aspects such as cognitive diagnosis, instructional design, classroom feedback, and personalized support, it explores effective application pathways for enhancing teaching quality and efficiency. The aim is to shift teaching from experience-driven to data-driven, thereby promoting high-quality development in higher education.

2. Technological background and theoretical foundations

2.1. Principles of eye-tracking technology and its educational applications

Eye-tracking technology is a behavioral research tool that analyzes individuals' visual attention and cognitive processes by recording eye movement trajectories ^[5]. The basic principle involves using infrared camera systems to capture changes in eye position during visual fixation and calculating gaze points through algorithms to generate data such as gaze paths and heat maps. Common eye-tracking indicators include fixation points, fixation duration, regression rate, and pupil diameter changes. These variables collectively reflect how individuals allocate attention and experience cognitive load while processing visual information ^[6].

In educational settings, eye-tracking technology enables the visualization and quantification of the learning process, effectively compensating for the traditionally unobservable aspects of student learning behavior in the classroom ^[7]. By defining Areas of Interest (AOIs) within instructional materials, researchers can perform quantitative analyses on students' gaze behavior in specific content regions. This allows for assessment of their attention to key concepts and identification of comprehension difficulties, providing real-time feedback to inform instructional design.

2.2. Cognitive psychology foundations for instructional optimization

The effective application of eye-tracking technology in teaching relies on robust cognitive theories as interpretive frameworks. Among them, Cognitive Load Theory is widely utilized in instructional design ^[8]. This theory posits that individuals have limited working memory capacity during learning. If instructional materials are poorly designed and exceed this capacity, learning efficiency deteriorates. Cognitive load is categorized into intrinsic, extraneous, and germane load. Extraneous load, which is mainly influenced by how information is presented, is a key variable that can be regulated through instructional design. Eye-tracking data provides a quantifiable method for dynamically assessing cognitive load. Educators can use this data to redesign content and better manage students' cognitive load, thereby enhancing learning outcomes (details in **Figure 1**).

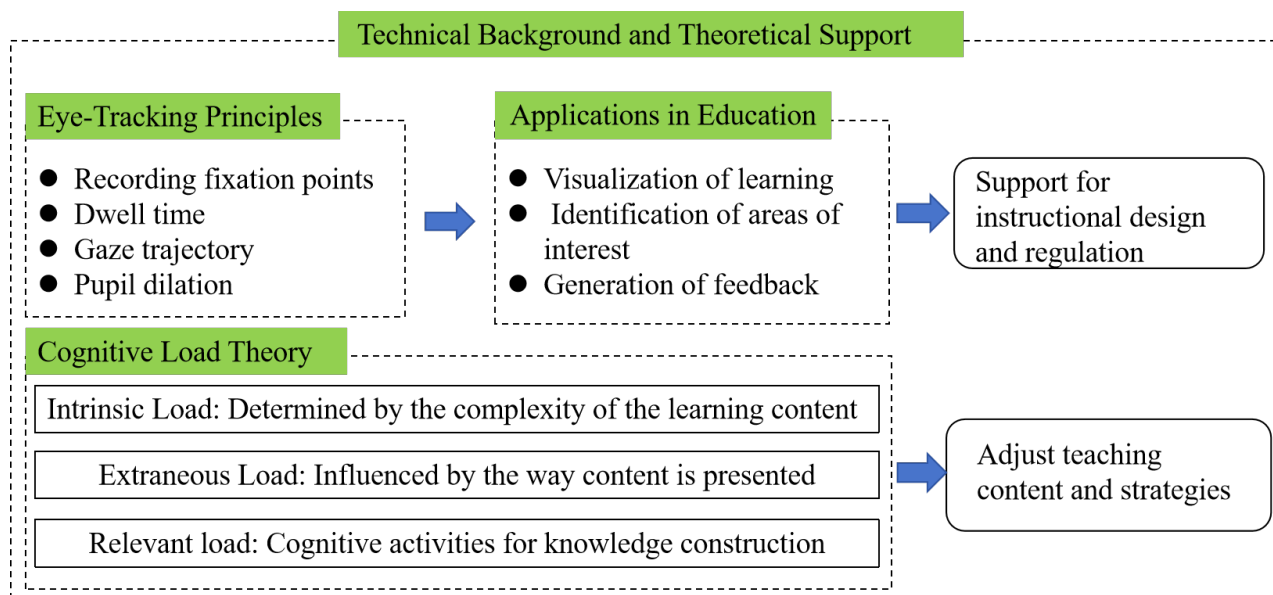


Figure 1. Applying eye-tracking technology and cognitive load theory.

3. Exploratory practice in teaching reform

This study attempts to integrate eye-tracking technology into mathematics teaching reform. By combining real classroom scenarios, it explores application pathways in areas such as instructional design optimization, classroom regulation, personalized support, and dynamic feedback, aiming to enhance teaching precision and learning effectiveness.

3.1. Accurately identifying students' cognitive barriers

Eye-tracking technology can be used to identify cognitive bottlenecks students encounter during the learning process. Focusing on key topics in Advanced Mathematics such as the definition of limits, definite integrals, and Taylor series, students were tasked with browsing courseware, watching instructional videos, and completing example problems. Their gaze paths and fixation durations were recorded using screen-based eye trackers. The analysis revealed that during multi-step derivations, students often displayed abnormally prolonged fixations at the proof steps of limits, indicating a high cognitive load. Additionally, frequent gaze shifts between diagrams and formulas suggested an unstable connection between geometric imagery and algebraic expressions. Although visual cues were present in the courseware, students' attention remained focused on textual descriptions while neglecting critical formulas and diagrams, exposing inefficient information extraction strategies and goal misalignment.

3.2. Optimizing the design and presentation of instructional content

Eye-tracking technology can provide effective feedback for instructional content design, helping teachers identify students' attention patterns and information processing characteristics, thereby optimizing content presentation and enhancing guidance.

In courseware design, content is no longer presented all at once but is broken down into step-by-step derivations with dynamic annotations. Complex formulas and reasoning processes are divided into logical units and displayed sequentially with animations to help students understand at a cognitive pace. Critical variables,

conclusion points, and easily confused segments are highlighted using visual means such as color, font, and graphics to focus attention on core information, reduce cognitive load, and prevent distraction.

Teaching strategies have also shifted from concept-first approaches to problem-oriented and context-based introductions. By presenting real-world mathematical problems, students are guided to naturally transition into knowledge formation during the problem-solving process, enhancing goal awareness and structural learning. This “learning through application” approach aligns better with students’ cognitive development and supports knowledge construction and transfer.

3.3. Establishing a dynamic classroom feedback mechanism

Embedding eye-tracking technology into classroom teaching enables real-time perception of students’ learning states and dynamic regulation of instructional pacing. Using portable eye-tracking devices, the gaze behaviors of selected students were monitored during class.

When a particular topic elicited short fixations or frequent regressions in the corresponding courseware area among most students, the teacher could infer comprehension difficulties and respond by slowing down, adding examples, or facilitating immediate Q&A sessions. Teachers could also adjust blackboard writing order and content layout based on students’ gaze paths to better match the rhythm of information intake.

This mechanism enables real-time, data-driven instructional feedback, moving away from one-way lecture-based models and significantly improving the interactivity and adaptability of teaching.

3.4. Supporting personalized learning resource recommendations

Eye-tracking technology has the potential to reveal learners’ cognitive styles and information processing preferences, providing data support for personalized learning resource recommendations.

For instance, students whose gaze paths concentrate on dynamic visual areas and exhibit smooth eye movements tend to prefer image-oriented materials, while those with longer fixations on text or formula regions may be more suited to logic-based learning approaches. Based on such eye-tracking features, students can be matched with resources that better align with their cognitive styles, such as interactive diagrams, structured derivation tasks, or concept map navigation, thereby improving learning efficiency and motivation.

3.5. Facilitating teacher reflection and professional development

Eye-tracking can also serve as a tool for supporting teachers’ professional development. By recording teachers’ gaze behaviors during lesson preparation and delivery, such as courseware browsing, blackboard writing, and student interactions. Thus, teachers can analyze attention distribution to identify blind spots and habitual behaviors in their instruction.

The analysis showed that some teachers overly focused on lecture notes during class, paying insufficient attention to students’ facial expressions and reactions, which may hinder classroom interaction. By reviewing their own eye-tracking recordings, teachers can visually perceive these issues and consciously adjust their attention distribution strategies in future classes, thereby enhancing responsiveness and teaching flexibility.

4. Reflections and insights on teaching reform

Based on the preceding teaching practices and reflections, this paper summarizes four systematic and forward-looking insights for educational reform (see **Figure 2**).

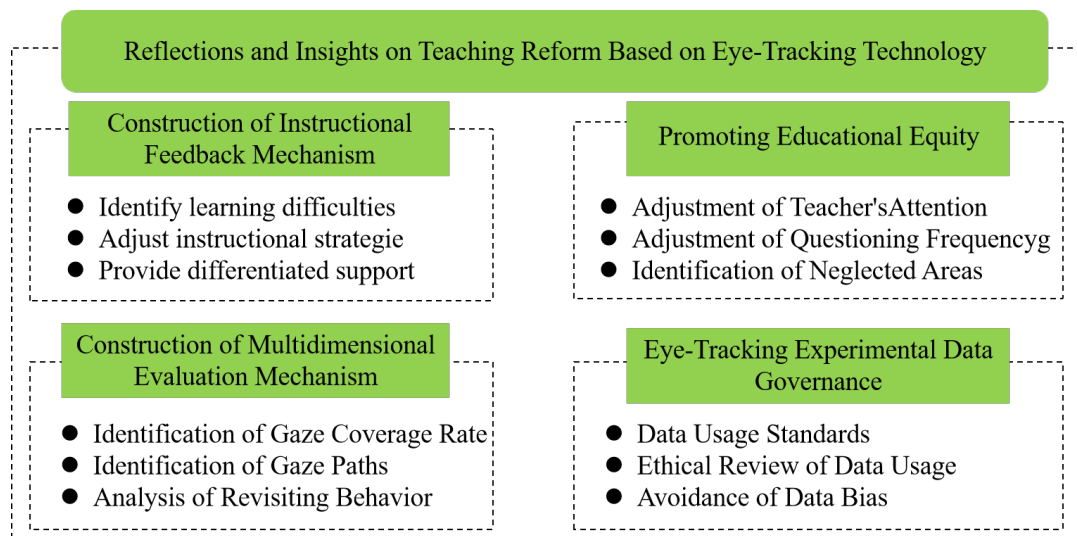


Figure 2. Framework diagram of reflections and insights on teaching reform.

4.1. Building a cognition-visualized teaching feedback mechanism

For a long time, the learning process has been regarded as a cognitive black box, with teachers often relying on experience-based judgment to assess student understanding, making precise intervention difficult. The introduction of eye-tracking technology enables the quantification, visualization, and analysis of students' visual attention behaviors during learning, providing new possibilities for constructing effective teaching feedback mechanisms^[9].

Teachers can utilize historical eye-tracking data to identify instructional difficulties before class, use real-time feedback to adjust teaching strategies during class, and offer differentiated support based on individual gaze patterns after class. This facilitates a shift from experience-driven to data-driven instruction, enhancing the adaptability of teaching and the relevance of student learning. Ultimately, it promotes the transformation of classroom instruction toward precision and intelligence.

4.2. Promoting equity and ethical decision-making in teaching

Teaching is not only a cognitive activity but also involves the distribution of ethical values. A teacher's attention distribution, frequency of questioning, and interaction patterns can lead to differentiated impacts on students. Eye-tracking data provides a quantitative basis for revealing these potential inequalities.

By analyzing the distribution of teachers' gaze behavior in class, it is possible to uncover tendencies such as disproportionate attention to active students or the neglect of average or quiet students. This data-driven reflection mechanism helps teachers balance efficiency with fairness in instructional decision-making, fostering ethical awareness and creating a more inclusive, diverse, and equitable teaching environment.

4.3. Developing a process-oriented, multi-dimensional evaluation system

Current evaluation systems in university mathematics education largely focus on summative outcomes, neglecting students' cognitive efforts and strategic changes throughout the learning process. Eye-tracking technology provides a practical data foundation for constructing process-oriented evaluation mechanisms. By analyzing students' gaze behaviors during courseware browsing, video learning, and problem-solving, key evaluation indicators can be extracted, such as fixation coverage on core content, logical consistency of gaze paths, frequency of regressions, and distribution of fixation durations. These indicators can not only inform teachers' instructional adjustments but also serve as feedback for students to optimize their learning strategies.

4.4. Addressing ethics and data governance in educational technology applications

When using eye-tracking devices to collect data on students' learning processes, safeguarding their privacy, data security, and informed consent becomes an unavoidable issue in technological applications. Higher education institutions should establish clear data usage protocols and ethical review mechanisms to ensure that students participate in data collection voluntarily and with full knowledge. Furthermore, when using eye-tracking data for assessment or categorization, care must be taken to avoid replacing individual understanding with data labeling, thereby preventing the emergence of new forms of digital bias. Only by finding a balance between technological rationality and humanistic care can the healthy and sustainable development of educational technology truly be achieved.

Funding

The 2024 Education and Teaching Reform Project, "Exploration and Practice of University Mathematics Teaching Reform Driven by Eye-Tracking Technology" (Project No.: JG2024047)

Disclosure statement

The authors declare no conflict of interest.

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