Visual Cueing and Eye-Tracking Technology in Education

Subjects: Education & Educational Research

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Visual cueing has been widely utilized in the practice of online learning. Visual cues like bold text, colors, arrows, or underlining are used to highlight important information in online materials. Online multimedia resources like video may use visual cues like blinking, highlighting, or zooming in on important details. Eye-tracking data can provide valuable insights into learners' visual behaviors, revealing what they are looking at, how long they focus on specific elements, and the sequences of their gazes' movements across different representations.

Keywords: Visual Cueing ; Eye-Tracking Technology ; Education

1. Introduction

Visual cues are extensively employed in the realm of education, ranging from color-coded reading materials to highlighted multimedia content [1]. People commonly use visual cues with the presumption that they positively influence students' learning. However, a critical question arises: is this presumption supported by evidence? Researchers have been exploring the effects of visual cues on learning for several decades, expanding their exploration to encompass various learning environments along with the advancement of learning technology—from paper books to multimedia material and from online education to virtual-reality education. Their findings suggested that visual cues effectively direct students' attention and facilitate their information-searching processes [2][3]. However, despite these promising results, it is essential to acknowledge that there is still no consensus on whether visual cues truly lead to a significant improvement in student performance.

In some studies, students achieved better performance, which was explained by the impact of visual cues in guiding students' attention away from irrelevant areas and saving their working memory for the key information, consequently leading to better learning results [4]. However, in some other studies, students only scored well in retention tasks. In transfer tasks, students' performance was not better [5][6], indicating that visual cues are only external models; students need to understand the information and build their own internal models to solve transfer tasks. As external tools, visual cues play a limited role in helping students understand, internalize, and apply information [5]. Some scholars' studies even denied the role of visual cues in helping students to focus on information. They pointed out that students may just be guided and not really see the information [7]

2. Visual Cueing in Online Learning

Visual cueing has been widely utilized in the practice of online learning. Visual cues like bold text, colors, arrows, or underlining are used to highlight important information in online materials [8][9]. Online multimedia resources like video may use visual cues like blinking, highlighting, or zooming in on important details [10][11]. The effects of visual cueing have been extensively investigated across various aspects, including different learning subjects (e.g., science, reading, problem solving, etc.) and diverse student groups (e.g., children, university students, low-performing students, etc.). Numerous studies have demonstrated the attention-cueing effect of visual cues [12][13]. For example, Jamet [6] employed an eye-tracking method to explore the impact of visual cues on students' problem-solving processes and found that visual cues effectively redirected students' attention toward relevant information while reducing their focus on unrelated areas. This allowed students to allocate more working memory to process the relevant information, leading to improved performance in retention tasks. However, the effect on transfer tasks was not significant. Moreover, the use of visual cues has been associated with a reduction in off-task behaviors in many studies, as students' attention is effectively directed to the related information area. A study conducted by Kercood et al. [14] implemented text highlighting and observed that it increased problem-solving time for females at risk for ADHD, decreased off-task duration, and improved the females' problem-solving performance. In addition to attention cueing and off-task duration decrease, visual cueing has

demonstrated a third important effect—information-searching. In a study by Ozcelik et al. [4], color was employed in multimedia learning, resulting in an increased performance of participants in both retention and transfer tasks. They analyzed students' eye movements during problem-solving processes and concluded that the use of color coding enhanced learning by facilitating the efficient location of corresponding information in illustrations and text.

Content-independent visual cueing has been studied, and three positive effects have been consistently verified, on attention cueing, off-task reduction, and information searching. However, beyond these effects, the role of visual cueing in facilitating understanding and improving performance remains a contentious topic. While some of the mentioned studies demonstrated that students achieved better performance with the help of visual cueing, not all research supports this finding. For example, Yeari et al. [3] conducted a study wherein text highlighting guided students' attention to the central text area, but no significant difference in students' processing and recall of central information was observed across the highlighted conditions. Cojean and Jamet [5] also verified the effect of visual cueing on information seeking, but they did not find any promotion of information understanding. They suggested that visual cues act as external cues, guiding students to the information but not necessarily ensuring its internalization. Similarly, Yang [10] reached a similar conclusion, noting that visual cueing effectively guides attention but may not optimize conceptual understanding or lead to improved performance. Furthermore, they have found evidence of a learning-interference effect of visual cueing on high-performing students, suggesting that for certain groups of learners, visual cueing may not be as beneficial and could potentially hinder their learning processes.

3. Eye-Tracking Technology in Education

The application of eye-tracking technology in educational settings dates back to the 1980s and 1990s, when researchers began using eye-tracking data to understand and analyze learners' comprehension processes when dealing with textual and pictorial information [15][16][17]. Van Gog and Scheiter [18] emphasized that eye-tracking data can provide valuable insights into learners' visual behaviors, revealing what they are looking at, how long they focus on specific elements, and the sequences of their gazes' movements across different representations. Eye trackers measure various eye-movement parameters, such as fixation duration, gaze duration, and transition frequency, to capture these behaviors objectively (for a comprehensive list of eye-movement metrics, please refer to the paper by Bednarik et al. [19]).

Researchers have used eye-tracking technology to investigate various aspects of learning behavior. For example, Brunyé and Taylor [20] explored how different learning goals may impact learners' outcomes. Schwonke et al. [21] observed changes in attentional behaviors when learners interacted with different representations and how these behaviors influenced learning. Eye-movement data have been deemed more objective and reliable than subjective self-reports [22].

Beyond attention, researchers have attempted to connect eye movements with other learning behaviors. Just and Carpenter [16] proposed the eye–mind hypothesis, suggesting that the eyes fixate on the areas where the mind is actively engaged. She and Chen [23] compared the effects of different multimedia methods on students' eye fixation behaviors and empirically verified a direct correlation between the duration of eye fixations and the depth of learning. Wu et al. [24] adopted eye-movement measures, such as total fixation duration, number of long fixations, and pupil size, to predict participants' performance. Susac et al. [22] analyzed students' eye fixations, reaction time, performance, and questionnaires to reveal their strategies in equation solving. Eye-tracking technology has been widely applied in online-learning research and is recognized as a powerful tool to study student learning behavior.

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