Effect of competitive environment on students' performance on physics conceptual questions: An eyetracking study

Shaona Zhou,[1,2,*,†] Qiuye Li,[1,3,‡,†] Yi Zhong,[1] Sihang Liang,[1]
Yongxuan Li,[1] Yifeng Ou,[1] and Xianqiu Wu[1,2,§,†]

[1]*Guangdong Provincial Key Laboratory of Quantum Engineering and Quantum Materials, National Demonstration Center for Experimental Physics Education, School of Physics, South China Normal University, Guangzhou, People's Republic of China*

[2]*National Research Center for Educational Materials (Elementary and Middle School Physics Materials Research), Guangdong Basic Research Center of Excellence for Structure and Fundamental Interactions of Matter, Key Laboratory of Atomic and Subatomic Structure and Quantum Control (Ministry of Education), South China Normal University, Guangzhou, People's Republic of China*

[3]*Department of Physics, The Ohio State University, Columbus, Ohio, USA*

(Received 27 December 2024; accepted 9 September 2025; published 24 October 2025)

Given the widespread presence of competition in educational settings and its complex impact on science learning, how students complete tasks in competitive environments has attracted a wide range of attention. The purpose of this study is to compare students' performance on physics conceptual questions in noncompetitive and competitive environments, focusing on both task outcomes and cognitive processing during task completion. There were 66 undergraduate students randomly assigned to one of two conditions (a noncompetitive group and a competitive group) to complete physics multiple-choice questions. The results displayed differences in undergraduate students' outcomes and eye movement behaviors when they completed physics conceptual questions under noncompetitive and competitive conditions. The noncompetitive group outperformed the competitive group in completing physics conceptual questions, while the competitive group spent less fixation time completing physics conceptual questions than the noncompetitive group. Additionally, the noncompetitive group displayed a larger number of revisits to the entire question than the competitive group. In summary, although students in a competitive environment completed physics conceptual questions more quickly, the accuracy was low, which could be described as "haste makes waste." Eyetracking data suggested that these differences might result from a greater emphasis on speed and reduced cognitive engagement in the competitive group.

DOI: 10.1103/y2cj-cvnb

I. INTRODUCTION

Human beings are usually faced with different kinds of competition in their social activities. Competition is an integral aspect of peer interaction [1,2]. It remains closely related to learning performance and continues to be highly controversial [3–5], notably within the realm of education and schooling [6,7]. Numerous researchers have advocated for the positive impacts of peer collaboration over peer competition [8,9] and noted that excessively competitive learning activities may yield negative consequences [10,11]. However, competition is generally deemed an effective method to inspire individuals to learn and excel in certain educational contexts [12–16]. Given the lack of consistent evidence regarding the effects of peer competition on education, whether competition serves as a beneficial or detrimental strategy for promoting learning has attracted the attention of researchers.

Most existing research on peer competition in education has primarily focused on its impact on academic outcomes, typically measured by final grades or standardized test scores [17–21]. In physics education, researchers have explored how competitive learning environments relate to students' academic achievement. Previous studies have examined the effects of competition on students' performance in physics classrooms [22–24]. These findings suggested that competition can promote students' achievement. However, Clark [22] also indicated that competitive settings in physics

*Contact author: zhou.shaona@m.scnu.edu.cn
†Present address: School of Physics, South China Normal University, Higher Education Mega Center, Guangzhou 510006, People's Republic of China.
‡Contact author: 2019021855@m.scnu.edu.cn
§Contact author: xqwu@scnu.edu.cn

classrooms increased anxiety. Additionally, some studies explored competition orientation and gender differences [25–27], as well as peer pressure and behavioral changes that occur in competitive environments [28,29]. While some studies have acknowledged that competition can affect motivation and academic performance under certain conditions, most studies remain centered on learning outcomes rather than the cognitive mechanisms underlying students' behavior in competitive settings. As a result, little is known about how competition influences key aspects of learning, such as visual attention, information processing, and engagement strategies. This gap limits our understanding of how competitive environments influence learning behaviors beyond the level of grades and test scores.

To address this gap, the present study investigated how competition affects students' performance on physics conceptual questions and their underlying cognitive processes. We applied eyetracking technology to gain deeper insights into students' cognitive processing during task completion. Eyetracking technology offers a more fine-grained analysis to understanding how competition influences students' attention allocation. This research contributes to the broader discussion on the role of competition in physics education and offers implications for instructional design in physics learning.

II. LITERATURE REVIEW

A. The role of competition in learning

Previous research suggested that the learning process is dynamic, as knowledge acquisition and application are influenced by various factors [30]. Among these, students' learning motivation is one of the crucial factors that promote engagement and academic success. Research indicated that learning motivation was pivotal in determining learning outcomes [31–33], as motivated learners exert greater effort, demonstrate higher attentiveness, and persevere more persistently in the face of difficulties [34]. In self-determination theory, competition is often viewed as a form of extrinsic motivation that can potentially undermine intrinsic motivation. Ryan and Reeve [35] discuss how external rewards and pressures, such as those found in competitive environments, can shift focus away from intrinsic learning goals to performance-based outcomes. Students' external rewards and pressures are usually combined with an environment of competition. Competition, recognized as a pervasive behavioral pattern, is a prevalent phenomenon across countries, cultures, and ethnic groups [36,37]. According to the American Psychological Association (APA) Dictionary of Psychology, competition is defined as "any performance situation structured in such a way that success depends on performing better than others" [38]. Psychological research has underscored the importance of studying competition for decades [36]. Besides, in the realm of education, competition has become an unavoidable reality, constrained by limited high-quality educational resources and driven by students' life goals [39].

The role of competition in learning has received increasing attention from researchers in recent years. Several scholars have suggested that peer competition is a pivotal element in the educational process [40,41]. For example, Ryan and Deci [33] noted that "peer-learning among students in higher education is increasingly a meaningful and important topic for research." However, research has yielded mixed results in substantiating competition as an effective strategy for learning. Several studies have indicated that peer pressure and competition can impact learning, with effects that can be detrimental or beneficial [42–44]. On the one hand, competition was reported to have a positive impact on learning in some studies [45,46]. He *et al.* [47] reported a significant positive correlation between class competition and academic achievement. Cagiltay *et al.* [48] found that competition in games enhanced learning and motivation. On the other hand, some studies have reported conflicting results, suggesting that competition has a negative impact on students' academic achievement [49,50]. Kohn [51] stated that excessively competitive learning activities could have some negative effects. A survey found that competition generated negative effects on the quality of student learning in New Zealand's elementary schools from the perspective of teachers [52]. Besides, other researchers have analyzed class competition from a dialectical perspective [53,54]. They reported that benign competition stimulates students' motivation, fosters mutual learning, and enhances individual performance. Conversely, vicious competition hinders collaboration among students and has detrimental effects on their academic achievement. In science, technology, engineering, and mathematics education, empirical studies have examined how the competitive environment affects student achievement in physics. Romanello [24] argued that well-designed competitive environments can enhance student engagement and performance in science learning. Clark [22] observed that competitive elements in conceptual physics classes enhanced student engagement but emphasized the importance of balancing pressure with adequate support. Agommuoh and Ekeoha [23] compared competitive learning methods and lecture methods in secondary physics classrooms and found that physics students taught in competitive learning settings had higher mean achievements than those taught physics using the lecture method. However, Clark [22] reported that competitive settings in a conceptual physics classroom increased anxiety, especially among students with lower self-confidence. This is consistent with research suggesting that learning environments emphasizing external performance goals may undermine motivation.

Taken together, competition, as one of the external motivators for learning, is a crucial and inevitable factor in the educational environment. However, the relationship between competition and learning is complex, and the impact of peer competition on students' learning remains controversial. Therefore, competition in the educational environment is a topic that warrants attention and further exploration. In addition, previous studies predominantly focus on learning outcomes rather than the cognitive processes involved in task performance. Less attention has been given to how competition influences students' cognitive strategies, attention allocation, and information processing while completing academic tasks. Investigating these processes is crucial for understanding how students navigate tasks in competitive versus noncompetitive conditions.

B. The role of competitive environments in performance goals

Students' achievement goals influence their learning motivation and behaviors [12]. Achievement goal theory is one of the predominant theoretical frameworks in motivation research [54–58], particularly in educational contexts [58–60]. It emphasizes the goals set by individuals themselves during the demonstration or development of their competence. According to this theory, the achievement goals are labeled as learning goals and performance goals [60]. Learning goals belong to the value-intrinsic quadrant, while performance goals belong to the value-extrinsic quadrant [61]. In addition, achievement goal theory emphasizes that students' academic goals influence their approach to learning opportunities and their consequent learning and achievement [62]. For example, both learning goals and performance goals can influence the depth of processing, test performance, and persistence at tasks [63]. Specifically, learners engaged in learning are driven by internal variables (e.g., personal interest) as they pursue learning goals [50,64]. They strive to enhance and improve their competence. Meanwhile, learners endeavor to comprehend and master the learning material, acquire knowledge, or develop a new skill [65]. On the contrary, in the pursuit of performance goals, learners are concerned with how others judge or compare them in terms of their ability. They want to know whether others perceive them favorably, seek to do better than others, and demonstrate their capabilities to others [50,66]. Learners are always seeking others' positive comments on their performance [66]. Therefore, learners usually compare themselves to others when they have a performance goal in their mind.

A competitive environment may motivate students to pursue performance goals instead of learning goals [66]. Overemphasizing competition may lead students to focus on external rewards (such as grades, rankings, etc.) and overlook intrinsic motivations (such as interest, curiosity, etc.) [11,67]. Therefore, students had to demonstrate their abilities relative to others. They may be inclined to seek positive evaluations of their abilities and avoid negative evaluations. Conversely, when students are not under competitive pressure, they are more likely to pursue learning goals and focus on the development of competence [11,67]. Some studies have explored the impact of competition on achievement goals. For example, Chen *et al.* [12] assigned students to competitive and noncompetitive conditions. It found that students in the competition group reported higher performance goals in a game-based learning environment, and students in the noncompetition condition tended to read the instructions carefully and repeatedly sought additional support to help themselves advance their conceptual understanding. Lam *et al.* [67] pointed out that competition induced worse self-evaluation after failure among Chinese students in a classroom setting. In addition, Dweck [57] postulated that performance and learning goals generated two different behavior patterns. He pointed out that learning goals were driven by intrinsic motivation, while performance goals were driven by extrinsic motivation. It is evident that competitive environments lead students to pursue performance goals and performance goals may also lead to changes in learning behaviors. However, empirical research on how competition influences attention allocation and cognitive strategies during task performance remains scarce.

Peer competition in educational settings has long been a topic of great interest to educators and researchers. Although there is extensive literature on the influence of peer competition on learning outcomes, such as test scores and grades, few studies have focused on the impact of competitive environments on the learning process or the task completion process. In physics education context, it often requires high cognitive processing in conceptual understanding and application, especially under the competition condition. Recent physics education studies have shown that learners' attention allocation patterns are closely linked to their conceptual understanding and problem-solving efficiency. For example, Becker *et al.* [68] demonstrated how gaze patterns reflect students' persistence and difficulties in interpreting graphs in kinematics tasks. Similarly, eyetracking evidence from Becker *et al.* [69] and Klein *et al.* [70] suggested that specific gaze behaviors are indicative of underlying reasoning strategies and can enhance the prediction of student responses beyond correctness alone. Exploring how competitive environment shapes students' attention allocations can offer meaningful insights for instructional design in physics education. This study aims to examine how competitive and noncompetitive environments influence students' cognitive processing strategies, particularly their attention distribution.

C. Eyetracking in understanding students' performance

To better understand students' cognitive processing, this study employs eyetracking as a process-oriented method revealing their attention and strategy use while completing physics conceptual questions in competitive and noncompetitive environments. The eyes play a crucial role in information intake, as eye movements reveal where a person is directing their visual attention. Given that competitive environments may influence students' behavior, such as cognitive engagement, attention allocation, and decision-making strategies, understanding how students visually process information during task completion is essential. Eyetracking technology provides a fine grained and objective method to examine these processes. Eyetracking research is primarily grounded in two key theoretical assumptions. One is the Eyemind assumption, which suggests that eye movements are closely linked to cognitive processing, meaning that where a person looks indicates what they are actively thinking about [71]. This assumption implies that by tracking gaze behavior, researchers can infer cognitive engagement and processing depth. The other one is the immediacy assumption, which further strengthens this connection by proposing that cognitive processing begins immediately upon fixation [72]. That is, when the eyes focus on an object, the brain starts to process the information in real time. This assumption highlights the role of eyetracking in revealing how quickly and effectively students engage with different parts of a task. Observing eye movements and shifts in visual attention among different regions can potentially provide valuable insights into cognitive processing [71].

In educational research, eyetracking methods have been widely applied in different subject backgrounds, such as mathematics, physics, chemistry, and biology. Over the past decade, eyetracking technology has played a crucial role in physics education research (PER), offering insights into students' visual attention patterns. Topics covered in previous eyetracking studies include comparing eye movement behavior during problem solving in different groups of students [73,74], revealing different visual strategies for interpreting (multiple) representations [75–77], and separating different phases during learning or problem solving [78–81]. For example, Wu and Liu [78] examined expertise differences using the Test of Understanding Graphs in Kinematics (TUG-K) and found that high-achieving students exhibited different eye movement patterns compared to low-achieving students. Similarly, Li *et al.* [81] detected the differences in preservice teachers' eye movement behaviors between the prediction condition and nonprediction condition. Besides, visual attention data can be utilized to separate different phases in the learning process. Gog *et al.* [82] found differences in attention allocation between the problem-orientation phase compared to the problem-solving phase, thereby reflecting the perceptual encoding processes and careful examination, respectively. All these results emphasize that visual attention allocation could be an important indicator for exploring the process of learning. Moreover, it provides a more nuanced comprehension of how students complete tasks by analyzing the results during students' eye movements. To sum up, compared with traditional assessing methods, eyetracking technology provides a more objective measurement method for researchers to monitor the entire learning process, not merely the learning outcome. In particular, eyetracking provides fine-grained information about students' behavior, such as their attention distribution, which can help us understand not only the time spent but also how this time is allocated to different cognitive tasks.

Previous studies have utilized various eyetracking metrics to analyze students' cognitive engagement. Fixation time has been used to assess cognitive engagement and information processing depth [72,82], while gaze transition and revisits help researchers understand information search strategies and cognitive shifts [83–86]. Building on these studies, our study employs eyetracking technology to investigate how competition influences students' attention allocation and cognitive strategies while completing physics conceptual tasks.

In our study, fixation time refers to the duration a participant spends focusing on a specific area of interest (AOI), providing insights into cognitive processing intensity. Revisit is defined as the participant's gaze returning to the targeted AOI from other AOIs. The number of revisits was calculated to obtain how many times the participants' gaze returns to the previously viewed AOI from other AOIs, reflecting reevaluation or reconsideration of information. By analyzing these metrics, we aim to uncover how competition influences students' performance on physics conceptual questions.

III. PURPOSE AND RESEARCH QUESTIONS

As competition is widespread in educational settings and its effects on learning seem to be complex, it is crucial to investigate how students perform in competitive environments. Conceptual understanding is a foundational instructional goal in physics education and it is reported that students' conceptual understanding is closely linked to their attention allocation patterns in previous research [68]. Although many studies have explored how competition affects motivation or learning outcomes, few have examined its impact on the cognitive processes involved in completing physics conceptual questions.

To address this gap, this study explores how competitive and noncompetitive environments affect students' performance on physics conceptual questions. We focus not only on students' learning outcomes (e.g., scores) but also on the process of their cognitive engagement. Specifically, we employ eyetracking technology to capture students' real-time visual attention when they are solving conceptual questions. This method enables us to examine how students distribute attention across question components (such as the question statement or answer options) and how often they revisit specific AOIs. This study examined two key eyetracking metrics: fixation time and revisits. The research questions are as follows:

1. How do undergraduate students' learning outcomes on physics conceptual questions differ under noncompetition and competition conditions?
2. How do undergraduate students' fixation times and revisits differ under noncompetition and competition conditions?

IV. METHOD

A. Design

In this study, participants were assigned to solve four multiple-choice questions selected from the Force Concept Inventory (FCI). The FCI is a validated and widely used diagnostic instrument designed to assess students' conceptual understanding of Newtonian mechanics. The FCI provides a theoretically and empirically appropriate assessment for evaluating students' performance in physics conceptual questions. Participants were divided into two groups: the noncompetitive group and the competitive group. The grouping was based on whether participants were exposed to a competitive condition during the process of completing the physics questions.

For the noncompetitive group, participants completed the physics questions individually without any competitive elements. Specifically, they were not informed about the performance or scores of other participants, creating a low-pressure environment where they could focus on the tasks at their own pace. This setting aimed to minimize external stressors, such as time constraints or peer comparison, which are often associated with competitive scenarios. For the competitive group, participants completed the same questions in pairs under competitive conditions. Each participant was seated at a separate computer in the same laboratory, and their task performance (accuracy and completion time) was compared directly with their paired counterpart. The student with the higher accuracy and shorter completion time was deemed the winner and received a reward. The winner in each pair received a monetary reward of RMB 10, while the other participant in the pair received RMB 5 as a participation reward. Moreover, all participants in the noncompetitive group also received RMB 5 for participation. It was designed to simulate authentic competitive pressure while ensuring that all participants received necessary compensation. This design required students in the competitive group to balance the need for accuracy with the need for speed to maximize their chances of winning.

Throughout the process of completing the physics conceptual questions, eyetracking technology was employed to record students' eye movement indicators, including fixation time and revisit frequency. By analyzing these metrics, we aimed to compare students' eye movement behaviors under noncompetitive and competitive conditions and explore how competition influences cognitive processing and decision making during the physics task.

Although it may seem intuitive that noncompetitive students spend more total time answering conceptual questions, it cannot provide insights into the specific cognitive strategies or areas of focus students use during the task.

B. Material

The Force Concept Inventory (FCI) (the version released in 1995) is a widely used 30-item multiple-choice assessment that evaluates students' understanding, misconceptions, and learning difficulties of the conceptual domain of force and motion. Each item has five possible choices, in which the incorrect choices reflect students' misconceptions of force and motion [87]. Four questions were selected involving one- and two-dimensional motion and Newton's laws (FCI questions 2, 8, 17, and 26). These four physics questions have been used to detect university physics students' misconceptions and their predictions of students' misconceptions in force and motion in our previous study [81]. The results showed that university physics students achieved the correct rate of these four questions only at about 75% (78.1%, 67.2%, 68.8%, and 79.7% for FCI question 2, 8, 17, and 26, respectively). This indicates that university students have mastered the relevant concepts to a certain extent, but there are still some misconceptions.

These four questions have been translated into Chinese and proofread by experts and teachers in our previous work [81]. The Chinese and English versions of these four physics conceptual questions are presented in Supplemental Material [88]. Each question consists of several elements: the text of a question, a graph if provided, five alternative responses to the question, and a submit button to enter the next question. All the above information was displayed on the computer screen with a fixed area for each element so that participants did not need to scroll the screen and it is also conducive to the subsequent analysis. An example is shown in Fig. 1. A checkbox was provided next to each option. Participants use the mouse to click one checkbox to record the answer and submit it with the submit button. Both the noncompetitive group and the competitive group had the same questions and received the same operational instructions.

C. Participants

The participants were undergraduate students enrolled in a normal university in the People's Republic of China. The students participating in this study were sophomores majoring in optoelectronics, electronic communication, and chemistry. These students had completed relevant

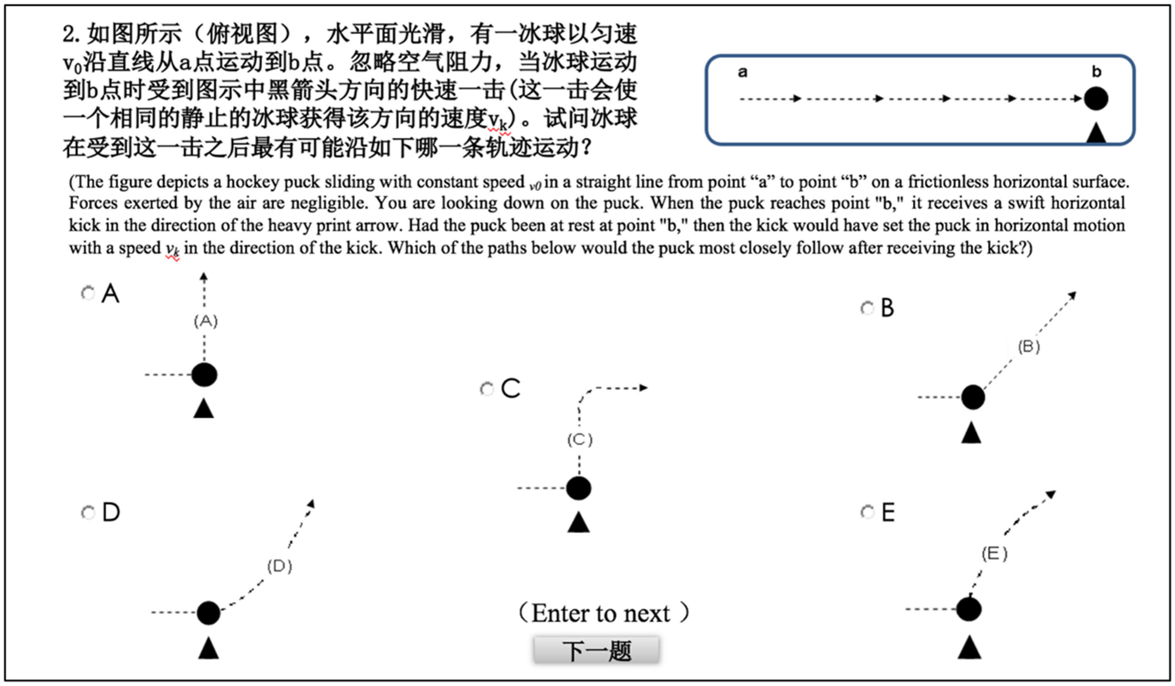

FIG. 1. Example of the multiple-choice questions used in the experiment. A checkbox was provided next to each option and a submit button was provided at the bottom of the screen.

courses in mechanics, electromagnetism, heat, optics, atomic physics, and more during their high school education. Specifically, the knowledge module of "force and motion" was predominantly covered in their first year of high school, with multiple rounds of review conducted in their third year. In addition, these sophomores had completed college physics courses in their freshman year of college and were currently enrolled in a physics laboratory course. Fundamental physics covers basic knowledge in mechanics, heat, electromagnetism, vibrations and waves, wave optics, special relativity, and quantum physics. It lays the necessary foundation for subsequent specialized courses and further acquisition of related knowledge. These shared academic backgrounds are expected to provide participants with a comparable foundation in physics knowledge and the skills required to complete physics conceptual questions.

All participants were aged between 19 and 20 years old. They were randomly assigned to either the competitive or noncompetitive group. Random assignment is commonly employed to minimize initial differences between groups. These students were admitted to universities based on their performance in the National College Entrance Examination. They had achieved a similar academic level and were distributed from the top 4.65% to 5.53% among the exam-taking population in the whole province. As some abnormal gaze data were deleted due to technical problems of the eyetracking apparatus or missing gaze data, the final dataset included 66 participants, with 32 in the noncompetitive group and 34 in the competitive group.

D. Apparatus

The eyetracking data were collected using the EYESO EX150 eyetracking equipment with a sampling rate of 150 Hz (sampling 150 times per second). A PC device was used to present the materials, and the eyetracking equipment was connected to the 22-inch PC device with 1920×1080 resolution and fixed under the computer monitor for data acquisition. When collecting data, participants sat in front of the monitor at a distance of 60 cm from the screen. Participants had free head and eye movement and responded to tasks using a mouse and a keyboard. EYESO STUDIO software installed on the PC device was applied to record and analyze the eye movement data.

E. Procedure

In the noncompetitive group, participants took the test individually, without any direct comparison to peers. To ensure the accuracy of eyetracking data and accommodate the limited availability of eyetracking devices, participants completed the tasks one by one. Each participant entered the experimental zone individually, where they completed the test while their eyetracking data were recorded. After one participant finished the task, the next participant began their session. This sequential approach allowed us to collect detailed eye movement data for each participant under controlled conditions. Conversely, to establish an interpersonal competitive environment in the competitive group, participants were tested in pairs. Within each pair, both participants completed the test simultaneously while seated at separate eyetracking devices. It is important to note that although the two participants in each pair completed the task at the same time, they did so independently, without any collaboration. To minimize the potential influence of one participant on the other, each participant was arranged to sit in a separate, isolated space with visual barriers. The competitive environment was created by informing participants that their performance (accuracy and speed) would be compared against their paired counterparts to determine a winner. The eyetracking data for all participants, whether in the competitive or noncompetitive group, were recorded individually using one eyetracking device per participant.

Upon admission into the experimental zone, all participants filled out a demographic information sheet (e.g., name, grade, student number, gender, and major) and were seated individually in front of eyetracking equipment. Each participant performed an eye calibration and validation test by following instructions on the monitor. During this process, each participant self-adjusted their seating position to the optimal distance from the screen to ensure accurate eyetracking calibration. The researchers provided detailed instructions and precautions before the formal stage of the experiment. During the test, the eyetracking equipment continuously recorded participants' gaze patterns and dwell time on different parts of the questions. The same set of four multiple-choice physics questions was used across both groups and the questions were presented in the same order for both groups.

Participants in the noncompetitive group received RMB 5 as a participation reward after completing the eyetracking recording phase, while those in the competitive group were rewarded based on their relative performance compared to their peers. The winners in each competitive pair, defined by higher accuracy and faster response, were rewarded with RMB 10. Specifically, if two competitors achieved the same response time, the one with higher accuracy was designated as the winner. If accuracy was equal, the competitor with a faster response time was declared the winner. In contrast, those who did not win in the competitive group each received RMB 5 as a participation reward. The entire experiment took approximately 20–25 min, with a detailed schedule provided in Fig. 2.

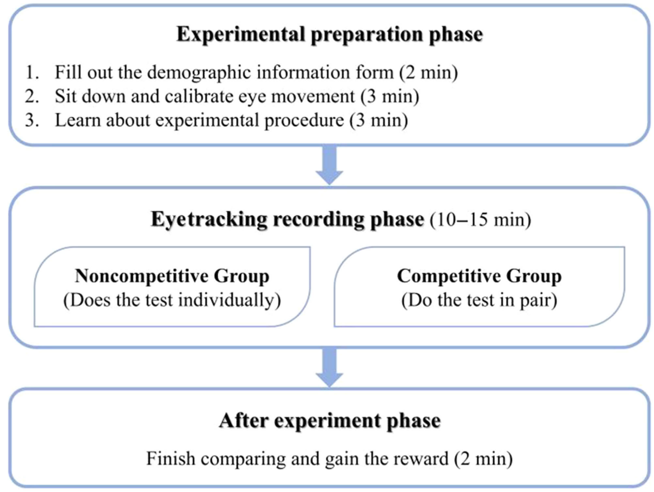

FIG. 2. Experimental procedure.

F. Data analysis

First, participants' responses in each group were recorded separately to identify the scores of the students' answers and misconceptions students held. Each of the four multiple-choice questions was allocated equal weight, with each question contributing 25% to the total score. Correct responses were assigned 1 point, while incorrect responses were assigned 0 points. The total score for each participant was calculated by summing the scores of the four questions, resulting in a total score range of 0 to 4. The four questions were designed to assess similar conceptual understanding and performance on conceptual questions in the given domain. Therefore, combining the scores provided a more robust measure of overall performance, reducing potential variability caused by individual question difficulty. This also helped determine whether there was a significant difference in students' performance on conceptual questions between the two groups.

For the data recorded by the eyetracking apparatus, different AOIs for each multiple-choice item were defined as follows to increase the accuracy and reliability of data analysis. The distribution of AOIs is illustrated in Fig. 3. The questions contained two types of areas of interest (AOIs): question statement AOI (a graph if provided) and option AOI (five options). The option AOI was further divided into the correct option AOI and the incorrect option AOI. The option AOI is just a term containing correct and incorrect AOI. Therefore, a total of four AOIs were defined for data analysis.

The study focused primarily on two eye movement indexes: fixation time and revisits. For each question, we calculated the fixation time for each AOI separately as well as the total fixation time across all AOIs within each question. We also calculated the number of revisits to each AOI and the total number of revisits across all AOIs in each question. For the overall four questions, the average fixation time and the total number of revisits are calculated. We also analyzed the average fixation time and number of revisits for each AOI across all four questions.

The fixation data were extracted using EYESO STUDIO software, which applies a Dispersion-Threshold Identification (*I-DT*). This algorithm automatically identifies fixations by grouping consecutive gaze points that fall within a spatial radius and meet a minimum duration threshold. Specifically, in our study, the maximum pixel dispersion from the fixation center was set to 45 pixels, and a fixation was only registered if it included at least 15 consecutive data points, equivalent to a minimum duration of approximately 100 ms (based on a sampling rate of

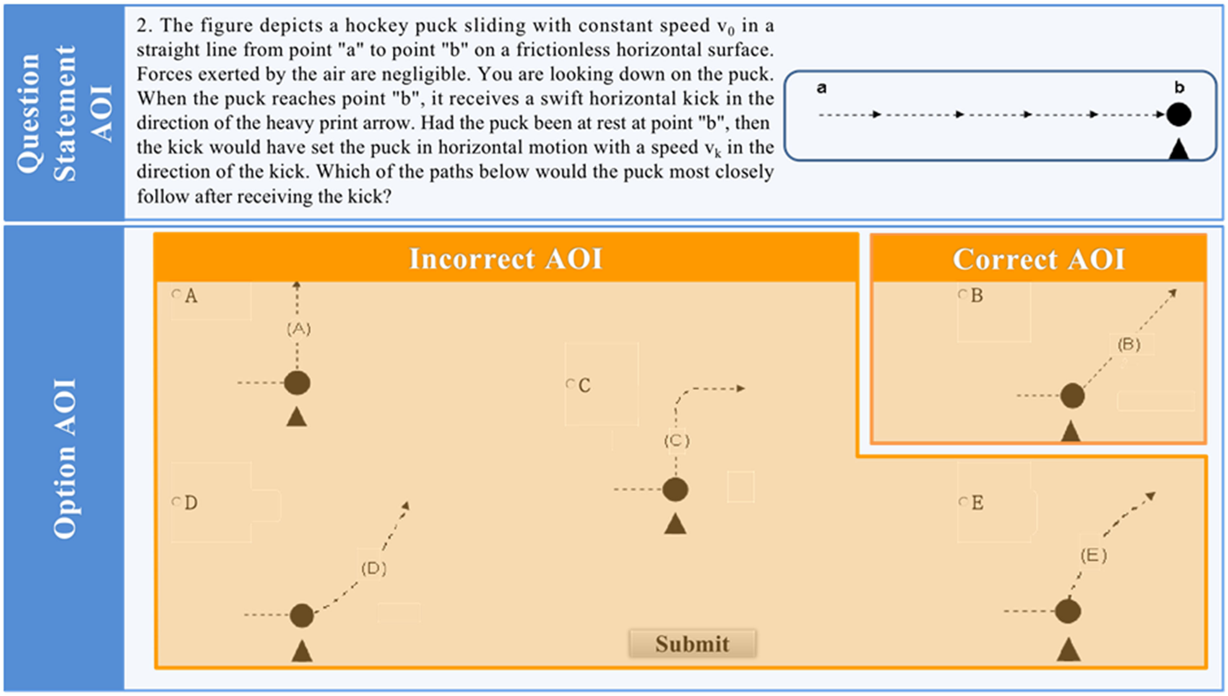

FIG. 3. Distribution of AOIs.

150 Hz). To be noted, we excluded gaze durations shorter than 100 ms as they do not represent stable fixations and are not typically considered valid for cognitive processing [71].

It is important to clarify that fixation time is distinct from the total time taken to complete the task. Eyetracking data allows for a fine-grained analysis of how students allocate their attention and employ cognitive strategies throughout the task. By examining where students focus their attention and for long, we aim to reveal the cognitive processes involved in completing physics conceptual questions and the cognitive processes cannot be inferred from total completion time data alone.

The datasets of fixation time and revisits in the AOIs were not normally distributed for all participants, as confirmed by the Kolmogorov-Smirnov test (See Table I). To compare the possible differences in eye movement indexes between the noncompetitive group and competitive group, the Mann-Whitney U tests were conducted on the total fixation time, fixation time for each AOI, the total number of revisits, and the number of revisits for each AOI. The effect size for each difference comparison was also calculated.

V. RESULT

A. Students' score on physics conceptual questions

Participants' total scores were calculated by summing the scores of the four questions to provide a comprehensive measure of their performance on physics conceptual questions. Table II presents descriptive statistics of students' scores for four questions and the data from the Mann-Whitney U test on total scores for four physics conceptual questions between the noncompetitive group and the competitive group. The results showed that there was a

TABLE I. Results of Kolmogorov-Smirnov tests of normality for fixation time and revisit frequency across different AOIs by group. Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

	Fixation time (seconds)				The number of revisits (times)			
	Noncompetitive ($n = 32$)		Competitive ($n = 34$)		Noncompetitive ($n = 32$)		Competitive ($n = 34$)	
	K	p	K	p	K	p	K	p
Total	0.188	0.016^{*}	0.172	0.024^{*}	0.195	0.010^{*}	0.192	0.013^{*}
In question statement AOI	0.191	0.014^{*}	0.199	$0.0.008^{**}$	0.173	0.016^{*}	0.180	0.019^{*}
In option AOI	0.222	$<0.001^{***}$	0.196	0.002^{**}	0.164	0.032^{*}	0.209	0.006^{**}
In correct option AOI	0.178	0.020^{*}	0.180	0.007^{**}	0.165	0.027^{*}	0.201	0.008^{**}
In incorrect option AOI	0.224	$<0.001^{***}$	0.189	0.003^{**}	0.179	0.012^{*}	0.156	0.036^{*}

TABLE II. Results of Mann-Whitney U test on the total score for the four physics questions between the noncompetitive group and competitive group. Note: $^{*}p < 0.05$.

	Noncompetitive group ($n = 32$)		Competitive group ($n = 34$)					
	M	SD	M	SD	U	Z	p	Cohen's d
Score	3.13	0.75	2.59	1.10	397.5	−1.97	0.048*	0.476

significant difference in the score for four questions between the two groups ($U = 397.5$, $p < 0.05$, Cohen's $d = 0.476$). Specifically, the score for the competitive group ($M = 2.59$, $\mathrm{SD} = 1.10$) was statistically lower than the noncompetitive group. ($M = 3.13$, $\mathrm{SD} = 0.75$). It indicated that the competitive environment might have a negative effect on students' performance on physics conceptual questions. To provide a more detailed view of students' performance, descriptive statistics (mean and standard deviation) for each of the four individual questions, separated by group, are presented in the Appendix Table VI.

B. Students' eye movement behaviors on physics conceptual questions

To explore differences in students' eye movement behaviors during their process of completing the physics conceptual questions in noncompetitive and competitive environments, we focused on the fixation time and the number of revisits for physics conceptual questions. In addition, we calculated fixation time and the number of revisits on the question statement AOI, the option AOI, correct option AOI, and incorrect option AOI, respectively. Table III presented the descriptive statistics of students' fixation time and the number of revisits.

1. Fixation time

The noncompetitive and competitive conditions were taken as independent variables, and the average fixation time of each question was taken as dependent variable. The results of Mann-Whitney U tests were presented in Table IV. It showed that there were significant differences in total fixation time between the noncompetitive group and the competitive group ($U = 376.50$, $p < 0.05$, Cohen's $d = 0.549$). As shown in Table III, the noncompetitive group ($M = 44.33$, $\mathrm{SD} = 16.22$) spent significantly more fixation time on the process of completing the physics questions than the competitive group ($M = 36.47$, $\mathrm{SD} = 13.50$). As for various AOIs, a significant difference in the fixation time on the question statement AOI was found ($U = 342.50$, $p < 0.01$, Cohen's $d = 0.671$) between the noncompetitive group and the competitive group. It suggested that the noncompetitive group spent more fixation time ($M = 20.15$, $\mathrm{SD} = 6.94$) than the competitive group ($M = 15.75$, $\mathrm{SD} = 5.48$). However,

TABLE III. Descriptive statistics of students' fixation time and the number of revisits.

	Fixation time (seconds)				The number of revisits (times)			
	Noncompetitive ($n = 32$)		Competitive ($n = 34$)		Noncompetitive ($n = 32$)		Competitive ($n = 34$)	
	M	SD	M	SD	M	SD	M	SD
Total	44.33	16.22	36.47	13.50	19.55	9.38	14.73	7.66
In question statement AOI	20.15	6.94	15.75	5.48	6.32	2.37	4.97	2.33
In option AOI	24.18	11.75	20.72	9.43	13.23	7.39	9.76	5.66
In correct option AOI	5.59	2.51	4.50	1.99	3.63	1.60	2.90	1.68
In incorrect option AOI	18.59	10.22	16.22	8.25	9.60	6.16	6.86	4.33

TABLE IV. Results of the Mann-Whitney U test on mean fixation time across all four questions between noncompetitive group and competitive group. Note: $^{*}p < 0.05$, AOI: area of interest.

		Noncompetitive ($n = 32$)		vs	Competitive ($n = 34$)	
		U	Z		p	Cohen's d
Fixation time	Total	376.50	−2.149		0.032*	0.549
	In question statement AOI	342.50	−2.585		0.010*	0.671
	In option AOI	453.00	−1.168		0.243	0.290
	In correct option AOI	406.50	−1.764		0.078	0.445
	In incorrect option AOI	469.00	−0.962		0.336	0.239

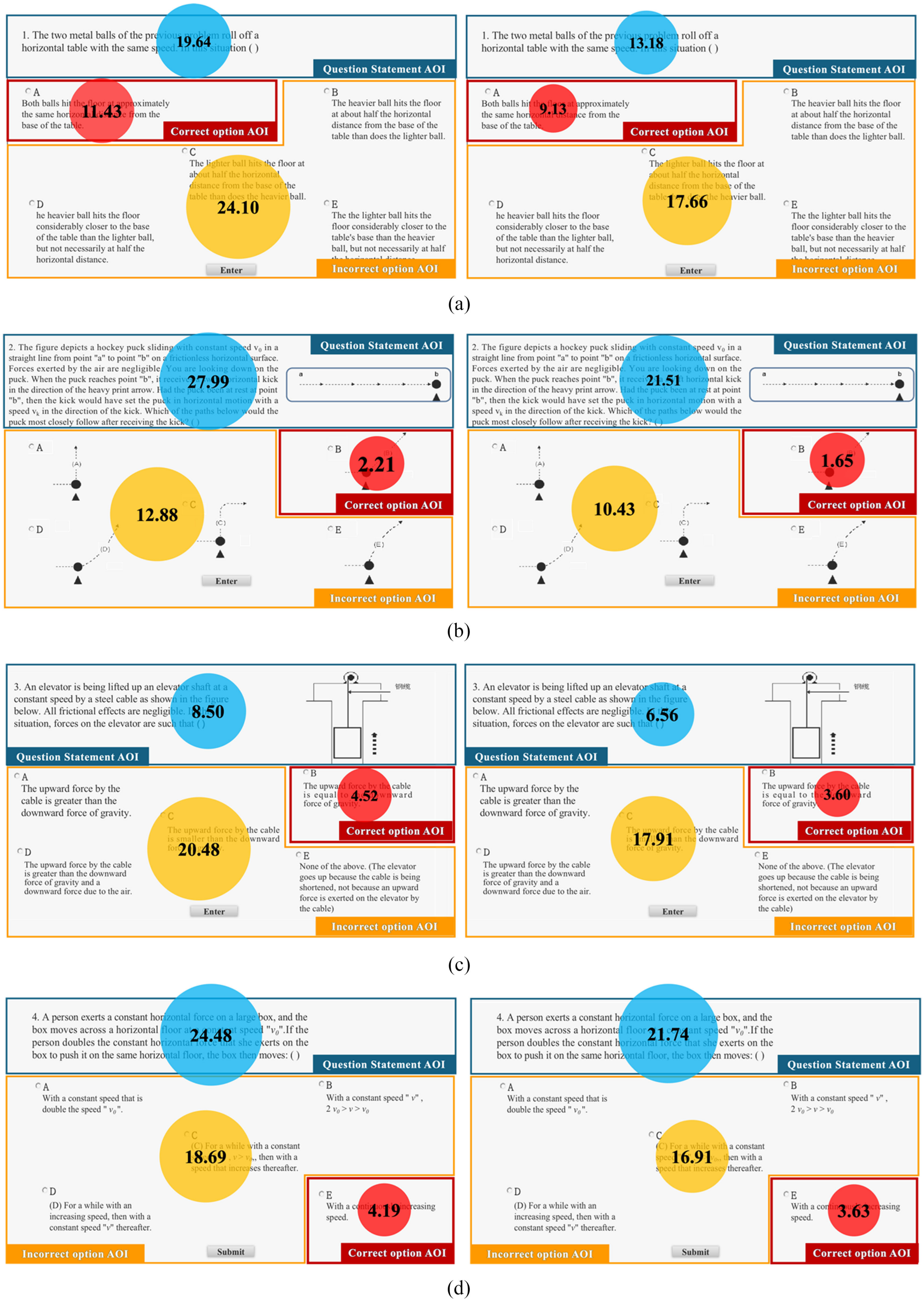

FIG. 4. Comparison of fixation time between the noncompetitive group (left) and the competitive group (right) for each physics conceptual question across different AOIs. (a) Question 1, (b) Question 2, (c) Question 3, (d) Question 4.

TABLE V. Results of the Mann-Whitney U test on the mean number of revisits across all four questions between the noncompetitive and competitive groups. Note: $^{*}p < 0.05$, AOI: area of interest.

		Noncompetitive ($n = 32$)		vs	Competitive ($n = 34$)	
		U	Z		p	Cohen's d
Revisits	Total	364.00	−2.310		0.021*	0.593
	In question statement AOI	370.00	−2.236		0.025*	0.572
	In option AOI	373.50	−2.188		0.029*	0.559
	In correct option AOI	401.50	−1.832		0.067	0.462
	In incorrect option AOI	379.50	−2.112		0.035*	0.538

there were no differences in fixation time on the option AOI ($U = 453.00$, $p = 0.243$, Cohen's $d = 0.290$), the correct option AOI ($U = 406.50$, $p = 0.078$, Cohen's $d = 0.445$), and the incorrect option AOI ($U = 469.00$, $p = 0.336$, Cohen's $d = 0.239$) between the two groups. Therefore, the difference in the average fixation time is primarily attributed to the difference in fixation time on the question statement AOI between the two groups.

Figures 4(a)–4(d) presented the fixation times for each of the four physics conceptual questions, comparing students in the noncompetitive and competitive groups. In each figure, the left panel showed data from the noncompetitive group, while the right panel showed the corresponding data from the competitive group. The shaded circles indicate the fixation time (in seconds) within specific areas of interest (AOIs), including the question statement AOI (blue), correct option AOI (red), and incorrect option AOIs (orange). Across all four questions, the noncompetitive group consistently displayed longer fixation times on question statements, correct options, and incorrect options than the competitive group. The competitive group displayed shorter fixations overall, possibly reflecting a rapid response approach.

2. Revisits

A Mann-Whitney U test was used to compare the difference in the number of revisits between the competitive group and the noncompetitive group. As can be seen from Table V, there was a significant difference in the total number of revisits ($U = 364.00$, $p < 0.05$, Cohen's $d = 0.593$) in the process of completing the question between the noncompetitive group and the competitive group. Specifically, the noncompetitive group ($M = 19.55$, $\mathrm{SD} = 9.38$) had more revisits than the competitive group ($M = 14.73$, $\mathrm{SD} = 7.66$) to an entire question. Moreover, the statistical results showed that the noncompetitive group had more revisits than the competing group, not only to the question statement AOI ($U = 370.00$, $p < 0.05$, Cohen's $d = 0.572$) but also to the option AOI ($U = 373.50$, $p < 0.05$, Cohen's $d = 0.559$). Within option AOI, the noncompetitive group ($M = 9.60$, $\mathrm{SD} = 6.16$) displayed a larger number of revisits to the incorrect option AOI ($U = 379.50$, $p > 0.05$, Cohen's $d = 0.538$) than the competitive group ($M = 6.86$, $\mathrm{SD} = 4.33$), while no statistical significance was found in correct option AOI ($U = 401.5$, $p > 0.05$, Cohen's $d = 0.462$) between the two groups. In other words, students in the noncompetitive group consistently shifted their attention to reviewing and comparing information across different AOIs, and revisited the question statement and incorrect option AOIs more frequently than those in the competitive group.

VI. DISCUSSION

The purpose of this study was to examine whether the competitive environment affects students' performance on physics conceptual questions. The study found that students under the noncompetitive condition outperformed those who completed physics questions under the competitive condition. For the process of completing the physics questions, two groups of students exhibited distinct patterns of cognitive strategies with different eye movement behaviors. The findings provide valuable insights into how competitive environments may influence students' conceptual performance and cognitive strategies based on the relatively small sample size.

A. Differences in students' performance on physics conceptual questions

Regarding the first research question, our study revealed that the noncompetitive group achieved a significantly higher score in completing physics questions compared to the competitive group. It indicated that a competitive environment may negatively affect students' performance on physics conceptual questions. In a competitive environment, students experience increased pressure, which may have a negative impact on students' academic performance [44,45]. However, findings from previous studies regarding the role of competition in learning tended to be inconsistent. Some literature suggested that competition in education may promote students' learning [64,89], with individual competition reported to have a positive impact on students' academic achievement [44,45]. Conversely, other sets of studies have revealed that competition has a negative impact on students' academic performance [49–51]. The results of the present study supported part of the previous research results. The FCI can be somewhat confusing, which may make it harder for students to identify and eliminate misconceptions when answering in a competitive setting.

It should be recognized that the role of competition is complex in an educational context. We believed that the impact of competition on students might be related to other factors, such as the education level of the participants, the content of the learning material, competition modes, and the difficulty of the task, etc. For example, a study reported that the students in the competitive condition performed better in the easy tasks than their counterparts in the noncompetitive condition. In contrast, they performed slightly worse on the difficult tasks than the students in the noncompetitive condition [67]. The four questions from FCI used in this study presented a certain level of difficulty, thus students did not perform to their expected level in the competitive environment. A meta-analytical study suggested that peer competition might be beneficial to learning in general and might not have additional benefits in learning contexts [90]. Consequently, the impact of competition on students' academic achievement remains controversial, and its internal mechanisms require further investigation. Future research is necessary to explore the multifaceted nature of competition in learning, and to determine the conditions under which competition is more or less effective [91,92].

B. Differences in students' eye movement behaviors

The results of the fixation time and revisits showed the possible effects of competition on students' eye movement behaviors during the process of completing physics conceptual questions. As for the fixation time, it was found that the competitive group displayed less fixation time on the entire question compared to the noncompetitive group, with significant differences found in the question statement AOI. It suggested that students spent less time completing the physics questions and paid less attention to reading the question statement in the competitive environment. For revisits, the results showed that the noncompetitive group displayed a larger number of revisits to the question statement AOI, option AOI, and incorrect option AOI. This means the noncompetitive group shifted their visual attention more frequently than the competitive group and were more likely to reprocess information about incorrect options.

From the result, the difference in total fixation time between the noncompetitive and competitive groups aligns with theoretical expectations. According to achievement goal theory, when learners pursue performance goals, they are more likely to focus on achieving favorable outcomes [50,66]. Previous literature suggested that time pressure and performance-focused goals in competitive settings tend to reduce the depth of cognitive engagement [10,57] and often emphasize speed over accuracy [58,64]. In contrast, students under noncompetitive conditions may adopt mastery goals, promoting deeper engagement and more strategic processing [50,64]. Our research result is consistent with these expectations and shows the observed pattern of shorter fixation durations and fewer revisits in the competitive group.

Eyetracking data provided a deeper understanding of the cognitive strategies underlying these differences. Eye fixation location reflects attention, while eye fixation time reflects the information processing and amount of attention. Previous research has pointed out that eye movements during cognitive processing depend on internal factors, such as individuals' abilities, intentions, and motivation [93,94]. In this study, undergraduates completed physics conceptual questions under competitive or noncompetitive conditions. The observed differences in eye movement behaviors might be attributed to the increased time pressure experienced by students in the competitive group compared to those in the noncompetitive group. As time pressure was an integral element of the competitive environment, it likely influenced students' attention allocation during the task.

As noted above, achievement goals affect learners' behavioral patterns [58], including the depth of processing, test performance, and persistence on tasks [64]. Some studies involving self-regulated learning noted that an achievement goal orientation assists in activating the learning strategies to be used and determining the amount of effort to be invested [95].

The observed differences in fixation time and revisit frequency align with prior research suggesting that competitive environments often induce time pressure and outcome-oriented behaviors [10,57]. In our study, we fostered a competitive atmosphere among students by offering additional monetary rewards to the winners with faster speed and higher accuracy in the competitive group. Such a competitive environment may encourage students to adopt performance goals rather than learning goals [67]. Students in the competitive group exhibited shorter fixation times on the question statement and fewer revisits. This pattern suggested that they might appear to complete the task quickly. They aimed to secure monetary rewards and hasten the pace of answering questions, resulting in a more rapid response strategy. However, students achieved lower scores in completing the physics questions compared to the noncompetitive group, which can be described as "haste makes waste." In a learning environment, speed competition among peers can either positively or negatively affect one's learning. As another study pointed out, speed competition among peers may incentivize them to invest more effort and maintain high motivation to achieve better learning outcomes, but it may also have negative impacts by inducing careless errors owing to excessive time pressures as well as anxiety.

In summary, students in the competitive group may have prioritized speed over accuracy, spending less time analyzing the question statement and making fewer revisits to confirm their understanding. This strategy, while potentially effective in tasks emphasizing rapid responses, might limit deeper cognitive engagement with the question, as suggested by the reduced attention to the question statement AOI. In contrast, students in the noncompetitive group appeared to adopt a more reflective approach, allocating more time and cognitive resources to thoroughly understand the question.

VII. CONCLUSIONS AND IMPLICATIONS

This present study explored the differences in undergraduate students' outcomes and eye movement behaviors when they completed physics multiple-choice questions under noncompetitive and competitive conditions. Overall, the noncompetitive group outperformed the competitive group in completing physics conceptual questions. Regarding eye movement behaviors, the competitive group spent less fixation time in completing physics conceptual questions, particularly paying less attention to reading the question statement compared to the noncompetitive group. Moreover, the noncompetitive group displayed a larger number of revisits to the entire question compared to the competitive group. To sum up, the competitive environment might impact students' learning. On the one hand, although students in a competitive environment completed physics questions more quickly, the accuracy was low, which could be described as "haste makes waste." On the other hand, students might adopt different task strategies depending on whether they are placed in a competitive environment.

The findings of this study have some implications for future studies and educational practice. First, this study revealed that peer competition might adversely impact students' performance on physics conceptual questions. The role of competition in education is complex, and the impact of competition on students might be related to many factors. Future research could further explore how different aspects of competition impact students, such as the mode of competition, the intensity of competition, and the identity of competitors. Concerning educational practice, competition, and exam pressure are unavoidable at present. Therefore, educators creating a positive competitive atmosphere and establishing a reasonable competitive mechanism are essential. Furthermore, teachers should pay attention to students' learning processes under competition and provide students with appropriate guidance and assistance, thereby reducing the negative effects of class competition and promoting a high level of academic achievement. Finally, this study demonstrated the potential benefits of using eyetracking technology in studying cognitive processes and developing effective answering strategies.

This study still has several limitations. First, the sample size was relatively small ($N = 66$), and all participants were from a single university with backgrounds in science and engineering. This limited sample size reduces the statistical power of the study to some extent. Replication studies with larger and more diverse populations are needed to verify the robustness and generalizability of the observed effects. Second, there was no pretest in the research design to assess students' accurate prior knowledge of the physics concepts. It was only deduced from students' performance in the National College Entrance Examination. It cannot confirm whether the noncompetitive group and the competitive group have the same level of understanding of the basic concepts. Future research should incorporate a pretest or adopt a within subjects design to control for individual differences. Third, the competition was structured as a pairing of two individuals in this study, and it involved direct competition between two individuals. Each participant was evaluated based on their performance relative to the other. However, different types of competition may affect students differently. Therefore, future research should explore how competition among multiple individuals affects students' cognitive engagement and task performance. Additionally, this study created a competitive atmosphere through external rewards. Although completing physics conceptual questions inherently involves the essence of competition, students may feel the lack of an atmosphere that intuitively represents real-time competitive outcomes. Future research could establish a more dynamic competitive setting, such as providing real-time progress updates on peers' performance to enhance engagement. Finally, future studies can conduct interviews as a complement to eyetracking methods to investigate why students perform specific visual behaviors.

ACKNOWLEDGMENTS

This work was supported by the 2024 Humanities and Social Sciences Planning Project funded by the Ministry of Education under (Grant No. 24YJA880105), Guangdong Provincial Undergraduate University Teaching Quality and Teaching Reform Project (2024) No. 9, Item 611, the Guangdong "14th Five-Year" Planning Project of Philosophy and Social Sciences under (Grant No. GD23XJY63), and the 2022 Guangdong Educational Science Planning Project (Special for Higher Education) under (Grant No. 2022GXJK175).

Any opinions expressed in this work are those of the authors and do not necessarily represent those of the funding agencies.

DATA AVAILABILITY

The data that support the findings of this article are not publicly available because they contain sensitive personal information. The data are available from the authors upon reasonable request.

APPENDIX: THE CHINESE AND ENGLISH VERSIONS OF THE FOUR PHYSICS CONCEPTUAL QUESTIONS

TABLE VI. Descriptive statistics of individual question scores by group.

	Noncompetitive group ($n = 32$)		Competitive group ($n = 34$)	
	M	SD	M	SD
Question 1	0.88	0.34	0.79	0.41
Question 2	0.63	0.49	0.38	0.49
Question 3	0.91	0.30	0.85	0.36
Question 4	0.72	0.46	0.56	0.50

[1] D. R. Clasen and B. B. Brown, The multidimensionality of peer pressure in adolescence, J. Youth Adolesc. **14**, 451 (1985).

[2] E. Vanderhoven, A. Raes, H. Montrieux, T. Rotsaert, and T. Schellens, What if pupils can assess their peers anonymously? A quasi-experimental study, Comput. Educ. **81**, 123 (2015).

[3] B. D. Bonta, Cooperation and competition in peaceful societies, Psychol. Bull. **121**, 299 (1997).

[4] K. Murayama and A. J. Elliot, The competition-performance relation: A meta-analytic review and test of the opposing processes model of competition and performance, Psychol. Bull. **138**, 1035 (2012).

[5] K. Murayama and A. J. Elliot, Further clarifying the competition–performance relation: Reply to D. W. Johnson et al. (2012), Psychol. Bull. **138**, 1079 (2012).

[6] D. W. Johnson and R. T. Johnson, *Joining Together: Group Theory and Group Skills*, 7th ed. (Allyn & Bacon, Boston, MA, 2000).

[7] D. W. Johnson and R. T. Johnson, An educational psychology success story: Social interdependence theory and cooperative learning, Educ. Res. **38**, 365 (2009).

[8] D. W. Johnson and R. T. Johnson, *Cooperation and Competition: Theory and Research* (Interaction Book Company, Edina, MI, 1989).

[9] H. R. Tenenbaum, N. E. Winstone, P. J. Leman, and R. E. Avery, How effective is peer interaction in facilitating learning? A meta-analysis, J. Educ. Psychol. **112**, 1303 (2020).

[10] E. L. Deci, R. Koestner, and R. M. Ryan, A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation, Psychol. Bull. **125**, 627 (1999).

[11] C. Ames, Classrooms: Goals, structures, and student motivation, J. Educ. Psychol. **84**, 261 (1992).

[12] C. H. Chen, V. Law, and W.-Y. Chen, The effects of peer competition-based science learning game on secondary students' performance, achievement goals, and perceived ability, Interact. Learn. Environ. **26**, 235 (2018).

[13] T. W. Malone and M. R. Lepper, *Making learning fun: A taxonomy of intrinsic motivations for learning, in Aptitude, Learning, and Instruction*, edited by R. E. Snow and M. J. Farr (Lawrence Erlbaum Associates, Hillsdale, NJ, 1987), pp. 223–253, 10.4324/9781003163244-10.

[14] Z. Qin and J. R. T. Johnson, Cooperative versus competitive efforts and problem solving, Rev. Educ. Res. **65**, 129 (1995).

[15] F. Y. Yu, *Promoting student learning and development in computer-based cooperative learning*, in *Proceedings of the International Conference on Computers in Education/International Conference on Computer-Assisted Instruction (ICCE/ICCAI)* (Taiwan, 2000), https://eric.ed.gov/?ff1=subComputer+Uses+in+Education&di=ED454818.

[16] I. C. Whittemore, The influence of competition on performance: An experimental study, J. Abnorm. Soc. Psychol. **19**, 236 (1924).

[17] J. D. Angrist, The perils of peer effects, Labour Econ. **30**, 98 (2014).

[18] M. A. Burke and T. R. Sass, Classroom peer effects and student achievement, J. Labor Econ. **31**, 51 (2013).

[19] J. Feld and U. Zölitz, Understanding peer effects: On the nature, estimation, and channels of peer effects, J. Labor Econ. **35**, 387 (2017).

[20] F. Lu and M. Anderson, Peer effects in microenvironments: The benefits of homogeneous classroom groups, J. Labor Econ. **33**, 91 (2015).

[21] R. Murphy and F. Weinhardt, Top of the class: The importance of ordinal rank, Res. Econ. Stud. **87**, 2777 (2020).

[22] B. Clark, Effects of competition in the conceptual physics classroom, Master's thesis, Montana State University, Bozeman, MT, 2018.

[23] P. C. Agommuoh and P. A. Ekeoha, Competitive and reciprocal peer tutoring learning methods: Ways of improving secondary school physics students' achievement in Abia state, Rivers State Univ. J. Educ. **26**, 1 (2023), https://rsujoe.com.ng/index.php/joe/article/view/172?utm.

[24] T. Romanello, Collaborative competition? A great way to teach and motivate, Phys. Teach., **43**, 76 (2005).

[25] U. Gneezy, M. Niederle, and A. Rustichini, Performance in competitive environments: Gender differences, Q. J. Econ. **118**, 1049 (2003).
[26] U. Gneezy, K. L. Leonard, and J. Rustichini, Gender differences in competition: Evidence from a matrilineal and a patriarchal society, Econometrica **77**, 1637 (2009).
[27] U. Gneezy and A. Rustichini, Gender and competition at a young age, Am. Econ. Rev. **94**, 377 (2004).
[28] L. Bursztyn, G. Egorov, and R. Jensen, Cool to be smart or smart to be cool? Understanding peer pressure in education, Rev. Econ. Stud. **86**, 1487 (2017).
[29] L. Bursztyn and R. Jensen, How does peer pressure affect educational investments?, Q. J. Econ. **130**, 1329 (2015).
[30] W. W. F. Lau and A. H. K. Yuen, Exploring the effects of gender and learning styles on computer programming performance: Implications for programming pedagogy, Br. J. Educ. Technol. **40**, 696 (2009).
[31] K. M. Y. Law, S. Geng, and T. Li, Student enrollment, motivation and learning performance in a blended learning environment: The mediating effects of social, teaching, and cognitive presence, Comput. Educ. **136**, 1 (2019).
[32] K. M. Y. Law, F. E. Sandnes, H. Jian, and Y. Huang, A comparative study of learning motivation among engineering students in South East Asia and beyond, Int. J. Eng. Educ. **25**, 144 (2009), https://ntut.elsevierpure.com/en/publications/a-comparative-study-of-learning-motivation-among-engineering-stud?utm.
[33] R. M. Ryan and E. L. Deci, Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being, Am. Psychol. **55**, 68 (2000).
[34] D. H. Schunk and B. J. Zimmerman, *Motivation and Self-Regulated Learning* (Lawrence Erlbaum Associates, Mahwah, NJ, 2007).
[35] R. M. Ryan and J. Reeve, Intrinsic motivation, psychological needs, and competition: A self-determination theory analysis, in *The Oxford Handbook of the Psychology of Competition*, edited by M. S. Bernstein and R. S. Mayer (Oxford University Press, New York, 2021), pp. 240–264.
[36] Z. Sun, T. Bai, W. Yu, J. Zhou, M. Zhang, and M. Shen, Attentional bias in competitive situations: Winner does not take all, Front. Psychol. **6**, 1469 (2015).
[37] P. T. Wong, L. C. Wong, and C. Scott, Beyond stress and coping: The positive psychology of transformation, in *Multicultural Perspectives on Stress and Coping*, edited by P. T. P. Wong and L. C. J. Wong (Springer, Boston, MA, 2006).
[38] G. R. VandenBos, *Competition, in APA Dictionary of Psychology* (American Psychological Association, Washington, DC, 2007), p. 204.
[39] J. R. Posselt and L. S. Ketchen, Competition, anxiety, and depression in the college classroom: Variations by student identity and field of study, J. Coll. Stud. Dev. **57**, 973 (2016).
[40] P. John, T. M. Buerck, and P. Elliott, Learning environment and learning styles: Nontraditional student environment and success in an internet-based versus a lecture-based computer science course, Learn. Environ. Res. **6**, 137 (2003).
[41] P. I. Ogbuehi and B. J. Fraser, Learning environment, attitudes and conceptual development associated with innovative strategies in middle-school mathematics, Learn. Environ. Res. **10**, 101 (2007).
[42] C. C. A. Chan, C. Pearson, and L. Entrekin, Examining the effects of internal and external team learning on team performance, Team Perform. Manag. **9**, 174 (2003).
[43] Y. Lee and P. A. Ertmer, Examining the effect of small group discussions and question prompts on vicarious learning outcomes, J. Res. Tech. Educ. **39**, 66 (2006).
[44] A. Rassuli and J. P. Manzer, Teach to learn: Multivariate analysis of perception of success in team learning, J. Educ. Bus. **81**, 21 (2005).
[45] J. E. Fisher, Competition and gaming: An experimental study, Simul. Gaming **7**, 321 (1976).
[46] J. M. Tauer and J. M. Harackiewicz, The effects of cooperation and competition on intrinsic motivation and performance, J. Pers. Soc. Psychol. **86**, 849 (2004).
[47] L. X. He, Q. Zhang, and C. K. Wang, The relationship between competition-cooperation and academic achievement: A mediator role of academic self-concept, Psychol. Explor. **31**, 172 (2011).
[48] N. E. Cagiltay, E. Ozcelik, and N. S. Ozcelik, The effect of competition on learning in games, Comput. Educ. **87**, 35 (2015).
[49] D. W. Johnson and R. T. Johnson, *Learning Together and Alone: Cooperative, Competitive, and Individualistic Learning*, 4th ed. (Allyn and Bacon, Boston, MA, 1994).
[50] C. Ames and J. Archer, Achievement goals in the classroom: Students' learning strategies and motivation processes, J. Educ. Psychol. **80**, 260 (1988).
[51] A. Kohn, *No Contest: The Case Against Competition*, 2nd ed. (Houghton Mifflin, Boston, MA, 1992).
[52] H. F. Ladd and E. B. Fiske, Does competition improve teaching and learning? Evidence from New Zealand, Educ. Eval. Policy Anal. **25**, 97 (2003).
[53] J. C. Burguillo, Using game-theory and competition-based learning to stimulate student motivation and performance, Comput. Educ. **55**, 566 (2010).
[54] S. Olitsky, The role of fictive kinship relationships in mediating classroom competition and supporting reciprocal mentoring, Cult. Stud. Sci. Educ. **6**, 883 (2011).
[55] J. Harackiewicz, K. Barron, and A. Elliot, Rethinking achievement goals: When are they adaptive for college students and why?, Educ. Psychol. **33**, 1 (1998).
[56] J. G. Nicholls, Achievement motivation: Conceptions of ability, subjective experience, task choice, and performance, Psychol. Rev. **91**, 328 (1984).
[57] C. S. Dweck, Motivational processes affecting learning, Am. Psychol. **41**, 1040 (1986).
[58] A. J. Elliot and C. S. Hulleman, Achievement goals, in *Handbook of Competence and Motivation: Theory and Application*, edited by A. J. Elliot, C. S. Dweck, and D. S. Yeager (The Guilford Press, New York, 2017), pp. 43–60.
[59] C. Senko, Achievement goal theory: A story of early promises, eventual discords, and future possibilities, in *Handbook of Motivation at School*, edited by K. Wentzel and D. Miele (Routledge, New York, 2016), Vol. 2, pp. 75–95.

[60] E. S. Elliott and C. S. Dweck, Goals: An approach to motivation and achievement, J. Pers. Soc. Psychol. **54**, 5 (1988).

[61] H. Song, R. Gao, Q. Zhang, and Y. Li, The nonlinear effect of time pressure on innovation performance: New insights from a meta-analysis and an empirical study, Front. Psychol. **13**, 1049174 (2023).

[62] B. A. Greene and R. B. Miller, Influences on achievement: Goals, perceived ability, and cognitive engagement, Contemp. Educ. Psychol. **21**, 181 (1996).

[63] M. Vansteenkiste, J. Simons, W. Lens, K. M. Sheldon, and E. L. Deci, Motivating learning, performance, and persistence: The synergistic effects of intrinsic goal contents and autonomy supportive contexts, J. Pers. Soc. Psychol. **87**, 246 (2004).

[64] B. A. Greene, R. B. Miller, H. M. Crowson, B. L. Duke, and K. L. Akey, Predicting high school students' cognitive engagement and achievement: Contributions of classroom perceptions and motivation, Contemp. Educ. Psychol. **29**, 462 (2004).

[65] M. V. Covington, Goal theory, motivation, and school achievement: An integrative review, Annu. Rev. Psychol. **51**, 171 (2000).

[66] C. Ames, Achievement attributions and self-instructions under competitive and individualistic goal structure, J. Educ. Psychol. **76**, 478 (1984).

[67] S. Lam, P. Yim, J. S. F. Law, and R. W. Y. Cheung, The effects of competition on achievement motivation in Chinese classrooms, Br. J. Educ. Psychol. **74**, 281 (2004).

[68] S. Becker, L. Knippertz, S. Ruzika, and J. Kuhn, Persistence, context, and visual strategy of graph understanding: Gaze patterns reveal student difficulties in interpreting graphs, Phys. Rev. Phys. Educ. Res. **19**, 020142 (2023).

[69] S. Becker, S. Küchemann, P. Klein, A. Lichtenberger, and J. Kuhn, Gaze patterns enhance response prediction: More than correct or incorrect, Phys. Rev. Phys. Educ. Res. **18**, 020107 (2022).

[70] P. Klein, S. Becker, S. Küchemann, and J. Kuhn, Test of understanding graphs in kinematics: Item objectives confirmed by clustering eye movement transitions, Phys. Rev. Phys. Educ. Res. **17**, 013102 (2021).

[71] M. A. Just and P. A. Carpenter, A theory of reading: From eye fixations to comprehension, Psychol. Rev. **87**, 329 (1980).

[72] K. Rayner, Eye movements and information processing: 20 years of research, Psychol. Bull. **124**, 372 (1998).

[73] M. Opfermann, A. Schmeck, and H. E. Fischer, Multiple representations in physics and science education—Why should we use them?, Educ. Res. **47**, 1 (2017).

[74] J. Scheid, A. Müller, R. Hettmannsperger, and W. Schnotz, Improving learners' representational coherence ability with experiment-related representational activity tasks, Phys. Rev. Phys. Educ. Res. **15**, 010142 (2019).

[75] B. Ibrahim and L. Ding, Sequential and simultaneous synthesis problem solving: A comparison of students' gaze transitions, Phys. Rev. Phys. Educ. Res. **17**, 010126 (2021).

[76] M. Kekule and J. Viiri, Students' approaches to solving R-FCI tasks observed by eye-tracking method, Sci. Educ. **9**, 117 (2018).

[77] P. Klein, J. Viiri, S. Mozaffari, A. Dengel, and J. Kuhn, Instruction-based clinical eye-tracking study on the visual interpretation of divergence: How do students look at vector field plots?, Phys. Rev. Phys. Educ. Res. **14**, 010116 (2018).

[78] C. J. Wu and C. Y. Liu, Eye-movement study of high- and low-prior-knowledge students' scientific argumentations with multiple representations, Phys. Rev. Phys. Educ. Res. **17**, 010125 (2021).

[79] K. P. Chien, C. Y. Tsai, H. L. Chen, W. H. Chang, and S. Chen, Learning differences and eye fixation patterns in virtual and physical science laboratories, Comput. Educ. **82**, 191 (2015).

[80] G. L. Chiou, C. Y. Hsu, and M.-J. Tsai, Exploring how students interact with guidance in a physics simulation: Evidence from eye-movement and log data analyses, Interact. Learn. Environ. **30**, 484 (2019).

[81] Q. Li, S. Xu, Y. Chen, C. Lu, and S. Zhou, Detecting preservice teachers' visual attention under prediction and nonprediction conditions with eye-tracking technology, Phys. Rev. Phys. Educ. Res. **18**, 010134 (2022).

[82] T. V. Gog, F. Paas, and J. J. G. Merriënboer, Uncovering expertise-related differences in troubleshooting performance, Appl. Cognit. Psychol. **19**, 205 (2010).

[83] M. J. Tsai, H. T. Hou, M. L. Lai, W. Y. Liu, and F. Y. Yang, Visual attention for solving multiple-choice science problem: An eye-tracking analysis, Comput. Educ. **58**, 375 (2012).

[84] A. Susac, M. Planinic, A. Bubic, K. Jelicic, L. Ivanjek, K. M. Cvenic, and M. Palmovic, Effect of students' investigative experiments on students' recognition of interference and diffraction patterns: An eye-tracking study, Phys. Rev. Phys. Educ. Res. **17**, 010110 (2021).

[85] Hyönä, The use of eye movements in the study of multimedia learning, Learn. Instr. **20**, 172 (2010).

[86] L. Mason, M. C. Tornatora, and P. Pluchino, Do fourth graders integrate text and picture in processing and learning from an illustrated science text? Evidence from eye-movement patterns, Comput. Educ. **60**, 95 (2013).

[87] D. Hestenes, M. Wells, and G. Swackhamer, Force concept inventory, Phys. Teach. **30**, 141 (1992).

[88] See Supplemental Material at http://link.aps.org/supplemental/10.1103/y2cj-cvnb for the Chinese and English versions of the four physics conceptual questions.

[89] R. B. Williams and C. A. Clippinger, Aggression, competition and computer games: Computer and human opponents, Comput. Hum. Behav. **18**, 495 (2002).

[90] J. C. S. Ho, Y. S. Hung, and L. Y. Y. Kwan, The impact of peer competition and collaboration on gamified learning performance in educational settings: A meta-analytical study, Educ. Inf. Technol. **27**, 3833 (2022).

[91] J. ter Vrugte, T. de Jong, S. Vandercruysse, P. Wouters, H. van Oostendorp, and J. Elen, How competition and heterogeneous collaboration interact in prevocational game-based mathematics education, Comput. Educ. **89**, 42 (2015).

[92] S. Vandercruysse, M. Vandewaetere, F. Cornillie, and G. Clarebout, Competition and students' perceptions in a

game-based language learning environment, Educ. Technol. Res. Dev. **61**, 927 (2013).

[93] R. Radach and A. Kennedy, Theoretical perspectives on eye movements in reading: Past controversies, current issues, and an agenda for future research, Eur. J. Cognit. Psychol. **16**, 3 (2004).

[94] K. Rayner, A. Pollatsek, J. Ashby, and C. Clifton, *Psychology of Reading*, 2nd ed. (Psychology Press, New York, 2012).

[95] A. Efklides, Metacognitive and self-regulated learning model, Educ. Psychol. **46**, 6 (2011).