

Students' eye-movement behaviors in solving physics problems with different information structures

Shaorui Xu^{1,2,3}, Qiuye Li^{1,2,*}, Yilin Chen⁴, Yang Xiao^{1,2,†} and Shaona Zhou^{1,2,‡}

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

²National 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

³School of Electronics and Communication, *Guangdong Mechanical and Electrical Polytechnic*, Guangzhou, Guangdong, 510550, People's Republic of China

⁴No. 1 Middle School of Jiexi County, Jiexiang, Guangdong 515499, People's Republic of China



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Students' problem-solving processes have attracted a wide range of attention. From an information processing perspective, we distinguish three types of physics problems: information-explicit, information-redundant, and information-implicit. This study explores students' visual behaviors when they were doing problem solving with these three types of problems. The participant sample included 90 high school students. Eye-tracking technology was used to record their eye movements while they solved each type of problem. The results showed that although students' accuracy did not differ significantly across the three problem types, their eye-movement behaviors exhibited differences. Students displayed longer total fixation times on information-redundant problems, particularly in the text and option areas, suggesting increased cognitive effort caused by extraneous information. In contrast, information-implicit problems elicited the highest number of revisits to the text area, indicating students' repeated attempts to extract obscured information. Moreover, students devoted more fixation time and more revisits to the correct option in information-explicit problems, whereas information-redundant and information-implicit problems resulted in longer fixation and more revisits to incorrect options. These findings indicated that students' visual attention patterns were influenced by the information structures of the physics problems, even though their performance outcomes did not significantly differ. The study highlights the importance of problem design in supporting students' effective reasoning and information integration.

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I. INTRODUCTION

The exploration of human problem solving has constituted a focal point within the realm of cognitive science. Initially, research was concentrated within specific domains, such as physics, algebra, and computer programming [1]. Problem solving in these domains involved an extensive repository of specialized knowledge and relied on generally agreed-upon logical principles. Over the past few

decades, problem solving has been increasingly recognized as a pivotal aspect of science education. It fosters higher-order cognitive skills such as scientific reasoning, rule identification and application, and the strategic coordination of knowledge to achieve goal states [2]. In the research areas mentioned above, two main research directions in problem solving have emerged. On one hand, there is a predominant emphasis on the process of problem solving [3,4]. On the other hand, attention is directed toward the knowledge possessed by the problem solver and the organization of that knowledge [5–7].

The designation “problem” presents an array of descriptors for its definition and differentiation, encompassing terms such as “well-structured” and “ill-structured,” “domain-dependent” and “domain-independent,” “static” and “dynamic,” “interactive” and “analytical,” and further involving the “visual,” “creative” and “design” [8–11]. Although scholars have affirmed the existence of certain

*Contact author: 2019021855@m.scnu.edu.cn

†Contact author: 20092305002@m.scnu.edu.cn

‡Contact author: zhou.shaona@m.scnu.edu.cn

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universal capabilities in all types of problem solving, it has also been ascertained that distinctive abilities associated with solving specific types of problems exist [12]. Studies have shown that the types of tasks influence individuals' behaviors in the selection and integration of representations [13–15]. Hence, acquiring the proficiency to solve only specific types of problems does not ensure the mastery of the competencies essential for solving others [16]. Consequently, it is imperative to study the cognitive processes involved in addressing different types of problem categories, as this is crucial for promoting the development of students' problem-solving skills [17]. To better understand how the information structure of physics problems influences students' attention distribution, this study adopts a problem classification approach rooted in Roegiers' situation typology framework [18]. This model highlights the role of how information is presented in a problem context, providing a conceptual foundation for distinguishing between problems with explicit, redundant, or implicit information.

Utilizing eye-tracking technology provides an attractive and powerful tool for revealing the intrinsic cognitive processing in student learning [19]. Numerous studies employ eye-tracking techniques to concentrate on diverse realms of learning, encompassing multimedia learning [20], conceptual learning [21], language acquisition [22], and category learning [23]. Considering that complex problem-solving endeavors require the integration of varied competencies, eye movements can provide a unique analytical perspective to enhance our comprehension of the field [19]. Especially, eye tracking allowed entry to process-related elements in certain situations without impeding the extraction and elaboration of information. Consequently, it provides the researcher with heightened insight into the participants' problem-solving conduct, thinking, and strategy in tackling physics problems [24].

II. LITERATURE REVIEW

A. Problem information in STEM domain contexts

To solve a problem, individuals should adeptly choose relevant information from the given problem and integrate it with their existing knowledge on the subject to derive a solution [25]. Consequently, information processing plays a crucial role during problem solving. In the endeavor of solving different problems, students have the flexibility to organize their solution process in different ways. For instance, students might first read through the entire problem before identifying the information relevant to its solution. Conversely, an alternative approach could involve skimming the text for the problem and analyzing the remainder of the text until relevant information is identified from the problem [26]. Furthermore, Littlefield and Rieser [27] proposed that students identify relevant information by thoroughly examining the problem and matching the

information required to solve the problem with what is presented in the problem text. They further demonstrated that students differ in the strategies they adopt during this process. More successful students tend to base their strategies on semantic analysis of problem features, whereas less successful students rely more on surface characteristics, such as information position. Such differences in information selection and filtering provide an important theoretical basis for understanding variations in visual attention during problem solving.

In educational contexts, especially in science, technology, engineering, and mathematics (STEM) domains, problems are often presented in the context of a story or real-life scenario [28], using verbal or contextual descriptions that embed various forms of information. Such problems might include numerical data, textual explanations, diagrams, and situational details that collectively define the task to be solved [29]. The way in which information is organized and presented within a problem exerts a strong influence on students' understanding and interpretation. In the field of mathematics, previous studies have proposed that the most fundamental differentiation between word problems and arithmetic lies in the incorporation of linguistic information. [30]. How linguistic details are presented, or the formulation of word problems, significantly shapes and impacts the problem's level of difficulty [31]. Notably, proficiency in solving word problems may be influenced by the attributes inherent in the problems themselves, such as the placement of unknown terms [32], the presence of authentic elements [33], and the type of problem [34].

Another aspect of word problems that has the potential to impact problem-solving accuracy is the inclusion of irrelevant information [35]. The presentation of extraneous details augments the complexity of resolving word problems within educational settings. Prevailing studies and national assessments reveal a pervasive difficulty in discerning relevant information from extraneous details among elementary and secondary students engaged in solving complex math word problems [34–41]. Marzocchi *et al.* [42] ascertained that the inclusion of literally irrelevant information had an influence on effective problem solving. Furthermore, students used more effort to deal with literally irrelevant information [43]. Therefore, the role of irrelevant information has become an important issue in problem-solving research [26].

While math problems and physics problems belong to different disciplines, they also share some similarities: they share common elements related to problem solving, the application of mathematical concepts, real-world context, critical thinking, and effective communication of solutions. Physics problems are also typically rich in information, integrating physical background, contextual details, and task-related questions. The information is related to scientific knowledge, daily life, or social hotspots. To simulate

authentic real-world situations, teachers have increasingly emphasized designing problems that require students to interpret and apply information in meaningful ways. However, such physics problems often contain both necessary and unnecessary information, as well as information that may be presented either explicitly or implicitly. In this context, explicitly presented information refers to quantities or relationships directly stated in the problem text, whereas implicitly presented information requires students to infer relationships or retrieve relevant physical principles that are not directly expressed. For instance, a problem may explicitly provide the initial velocity and time of motion but implicitly require students to identify the acceleration based on the given velocity and time. A study suggested that students who acquired scientific concepts paid more attention to appropriate information but paid less attention to irrelevant information. On the contrary, students who held misconceptions fixated more on misleading information but failed to select appropriate information [43].

B. Classification of physics problems based on situation typology

According to Xavier Roegiers' theory of integrated teaching (*enseignement intégré*) [18,44], he further explored the nature of problem situations and how they can be deliberately constructed within instructional contexts [45]. This approach aims to embed school-based learning into complex situations to promote the integration and transfer of academic achievements [46,47]. Building on this perspective, Roegiers proposed the situation typology as a refined analytical framework for understanding and designing such problem situations in education. He defined a complex or problem situation as a contextualized set of information that must be interpreted to complete a specific task, where the solution is not immediately apparent [48,49].

The core of the situation typology framework lies in its multidimensional analysis of problem situations, revealing their essential characteristics through three dimensions: discrimination parameters, content parameters, and adornment parameters [18]. Discrimination parameters refer to the structural characteristics that distinguish one problem situation from another, including the source and contextual features of the situation, the organization of knowledge elements, and the type of problem posed. For example, one problem may require proportional reasoning to determine acceleration from force and mass, whereas another may involve causal reasoning about motion under varying conditions. Content parameters describe the disciplinary knowledge involved and the level of cognitive demand required to achieve the intended task. For instance, a motion problem might involve applying Newton's second law, while another involves interpreting kinematic equations. Adornment parameters focus on how information is structured and presented within a given problem context. They encompass the form of contextual presentation and

the treatment of given conditions. For example, in a motion problem, quantities such as acceleration may be explicitly given, inferred from force and mass, or obscured by irrelevant contextual details. This typology offers a systematic method for analyzing and constructing problem situations in educational settings.

In the present study, we focus on the adornment dimension, as it captures how variations in information structures influence students' visual attention and cognitive processing. Within Roegiers' framework, adornment parameters concern the structure and clarity of problem statements, including factors such as lexical complexity, completeness of given information, and the presence of irrelevant or missing conditions. Based on this perspective, the given information can be categorized into three types: (i) clearly available information, where relevant conditions are explicitly stated; (ii) implicit or transformed information, where key relationships must be inferred or reconstructed; and (iii) redundant or distracting information, where additional details may increase cognitive load without contributing to the solution [18]. It is important to note that all problems share comparable reasoning structures (discrimination parameters) and disciplinary content (content parameters), with variation only in the presentation and handling of given information.

Based on this operationalization of the adornment dimension, we classified the physics problems into three types: information-explicit, information-implicit, and information-redundant problems. Information-explicit problems present all relevant information clearly and are directly applicable to the solution. Information-implicit problems require students to infer essential information from contextual cues, as the necessary information is not explicitly stated. Information-redundant problems include excessive or distracting information that may obscure the essential elements of the task and increase cognitive load. By aligning our problem classification with the adornment dimension of Roegiers' situation typology, we aim to explore how different information structures shape students' cognitive strategies and visual attention patterns during physics problem solving.

C. Eye-tracking insights into information processing during problem solving

Given the central role of information in problem solving, it is worthwhile to investigate how students process varying information structures. Eye movements provide insights into individuals' visual attention, indicating where their gaze is directed [23]. Monitoring real-time eye movements is an effective approach for investigating information processing during problem solving [8,50,51]. In accordance with the eye-mind hypothesis, gaze direction closely corresponds to the focus of attention during visual information processing [52]. Subsequently, the concentrated information is selectively retrieved and assimilated into the

working memory of the brain [53]. Utilizing eye-tracking methodology, researchers can quantify the distribution of visual attention among problem solvers and delve into their information processing, without disrupting the task, and allowing participants to engage with the problem in a natural manner [54–56]. Eye-tracking technology allows researchers to examine which elements of a visual stimulus participants attend to, the duration of their gaze, and the sequence of their observations. Such analyses provide valuable insights into cognitive processing during learning and problem solving. Education researchers have undertaken eye-tracking studies for numerous decades, intending to illuminate students' learning processes and problem-solving strategies.

Early eye-tracking studies mainly focused on reading processes [57,58]. Subsequently, the method has been increasingly applied to investigate learning and problem solving, particularly in the context of science and mathematics word problems [19]. Essentially, studies that employed eye-tracking techniques in reading are intimately linked to those employed in problem solving, as they collectively detected participants' visual attention and information processing of elements within the material [52,59–61]. Numerous studies have suggested that the semantic structure of word problems influences eye-movement patterns during reading [59,62–64]. For example, Hegarty *et al.* conducted several eye-tracking studies on mathematics word problems and found that different solution strategies are reflected in both accuracy and gaze patterns [54,55]. In more detail, unsuccessful problem solvers employing a direct-translation strategy would exhibit a more prolonged focus on the numbers and relational keywords. Conversely, the successful problem solvers use a problem-model strategy to allocate their attention more proportionally over the relevant text across the entirety of the problem. Furthermore, Verschaffel *et al.* [60] explored students' word problem solving, revealing that the order in which information is presented in a question can cause comprehension errors. Moreover, other studies have shown that individuals read more slowly in semantically more complex word problems [59,62]. Depending on the semantic structure of the word problem, some elements included in the question are fixated upon more frequently and for longer durations, such as numbers, keywords, relational terms, and contextual information [59,62,64]. The aforementioned studies suggest that recognizing, selecting, and processing relevant information are essential for the successful resolution of problems.

Eye-tracking studies have increasingly appeared in physics education research (PER) [65,66]. A systematic review emphasized the growing popularity of eye tracking in PER, demonstrating the potential of eye tracking in PER [23]. Earlier studies have determined that specific eye-movement patterns are correlated with success in problem solving [62,63]. Findings indicated that successful solvers

tend to direct their gaze selectively toward the areas relevant to the given task [44]. Likewise, individuals who attended to critical elements achieved success in solving problems related to logical reasoning. [55,67,68]. In a study on equation solving, students who possessed the knowledge of where to direct their gaze efficiently obtained the correct solution [69]. Furthermore, in physics contexts, expertlike performance is often characterized by more fixations on task-relevant areas and fewer fixations on redundant areas [70,71]. Ibrahim and Ding found that different kinds of synthesis problems were processed differently by students [15]. The differences between multiple-representation tasks were addressed in a study by Kekule and Viiri [13] in the context of kinematics. Wu and Liu [14] investigated how students coordinate their attention when presented with multiple representations of a motion process. All these results emphasize that visual attention allocation could be an important indicator for exploring information processing while solving problems.

Generally, eye fixation location reflects attention, and eye fixation time serves as an indicator of processing difficulty and the amount of attention. Longer fixation times may indicate deeper processing or increased complexity of the information being examined. Notably, fixation time varies depending on the type of information (e.g., texts or graphics) and the type of task (e.g., reading or problem solving). Additionally, fixation locations and durations offer insights into individuals' strategies, as well as their prior knowledge and experiences [72]. In this context, revisits refer to the eyes fixating within an area of interest (AOI), moving away from the AOI, and subsequently returning to fixate within the same AOI [73]. This measure reflects the reprocessing of the previous information by participants. The number of revisits reflects the frequency with which participants return to gaze at a specific target in the defined AOIs [65]. Scan path patterns exhibit individuals' cognitive strategies utilized in goal-oriented tasks [74]. These eye-movement indicators can reflect learners' cognitive processes of information processing and problem solving.

III. PURPOSE AND RESEARCH QUESTIONS

According to the design theory of problem solving of Jonassen [75], the nature of the problem, the way the problem is represented to the solver, and a host of individual differences in skill possession affect the problem-solving process. This study investigated how physics problems with different information structures (information-explicit, information-redundant, and information-implicit) influence students' problem-solving processes. These three types of problems were categorized based on Roegiers' situation typology [18], particularly the adornment parameter concerning the processing of known conditions, which distinguishes between explicit, implicit, and interfering information structures.

Although problem solving in physics has received substantial attention in prior research, most studies focus on well-structured problems with clear and sufficient information. Far fewer studies have examined how students process problems that contain redundant or implicit information, particularly from the perspective of information processing and integration.

To address this gap, the present study employs eye-tracking technology to explore students' visual attention and cognitive behaviors when solving physics problems with different information structures. By analyzing students' eye-movement patterns, including fixation time and revisit behaviors, we aim to gain insights into their underlying cognitive strategies. Accordingly, the study addresses the following research questions:

1. How do students' performances differ when solving information-explicit, information-redundant, and information-implicit physics problems?
2. How do students' eye-movement behaviors differ across the three types of physics problems?

IV. METHODOLOGY

A. Design and materials

In this study, three physics problems in the module of motion were involved, including the knowledge contents of "Description of Motion," "Uniformly accelerated Motion," and "Interactions." These three base problems (question 1, question 2, and question 3) were multiple-choice items and were selected from the Chinese college entrance

examinations of the past ten years. Each base question was constructed in three different information-structure formats: information-explicit, information-redundant, and information-implicit. Thus, the material pool consisted of nine items in total, representing three questions each presented in three structural variants (see details in the Appendix).

For example, the prototype for question 1 (Q1) is an information-sufficient physics problem, which consists of a textual description and an $x-t$ graph (displacement vs time). Q1 involves uniformly accelerated motion in a straight line for car A and uniform motion in a straight line for car B. The task focused on examining the interpretation skills of the kinematic graph. Students need to determine the displacement and velocity for both car A and car B from the $x-t$ graph and choose a reasonable description from the given four choices. Based on question 1 (information-explicit problem), it was modified to be an information-implicit problem by deleting the text information of "Car A moving uniformly accelerated and Car B moving uniformly." It is worth noting that the deleted text information could be extracted from the $x-t$ graph, and its absence did not make a difference to the plausibility of the given physics problem. On the other hand, we modified the question 1 information-explicit problem to the information-redundant one by adding a textual description of "The curve representing the displacement of car B is above that of car A between t_1 and t_2 ."

The added text relates to the information in the graph, but it is not necessary for the problem-solving process.

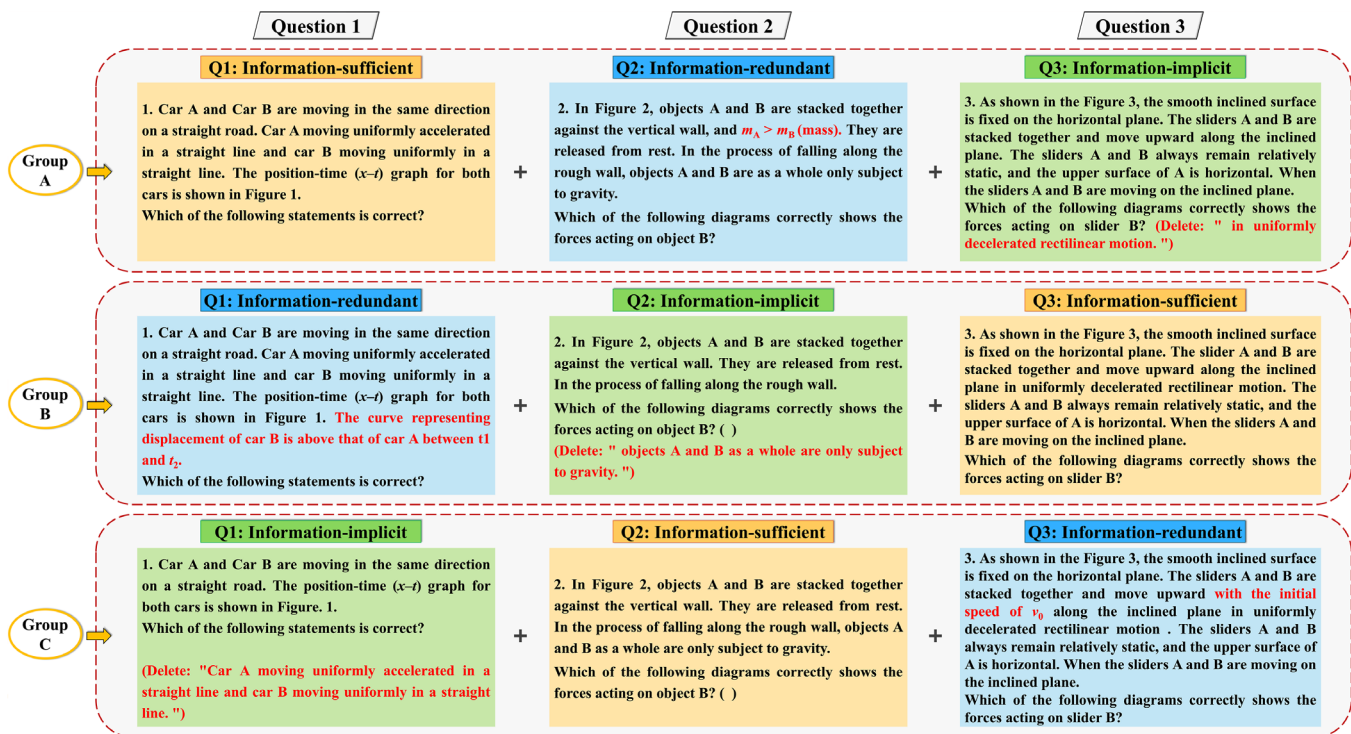


FIG. 1. Grouping of physics problems with different information structures (showing question statement only).

Similarly, question 2 (Q2) and question 3 (Q3) were both transformed into an information-implicit problem and an information-redundant problem from the information-explicit one. Therefore, the final material set consisted of three base questions, each presented in three structural formats. There were nine items in the present material, and the base question 1, question 2, and question 3 are presented in Fig. 1.

The nine items were divided into three separate groups according to the information covered in the item, namely, groups A, B, and C. Each group contained three physics problems with different information structures (information-explicit, information-redundant, and information-implicit) for different questions. The details of the groups are shown in Fig. 1. Group A included question 1 for information-explicit, question 2 for information-redundant, and question 3 for information-implicit. Group B included question 1 for information-redundant, question 2 for information-implicit, and question 3 for information-explicit. Moreover, group C included question 1 for information-implicit, question 2 for information-explicit, and question 3 for information-redundant. Each question consists of the following elements: the text of a question, a graph, four 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 convenient for the upcoming analysis.

B. Participants

A total of 99 high school students (52 females and 47 males) participated in the study. They were enrolled in the 10th grade (equivalent to first-year senior high school) at a high school in southern China. The students were approximately 15–16 years old at the time of the study. The students participating in our study came from three “regular classes” of the same academic level in high school. Based on students’ academic performance, Chinese high schools often divide classes into “advanced classes” and “regular classes.” Generally, students in advanced classes achieve more outstanding academic performance, and these classes are fewer in number. More students belong to regular classes, where their performance levels are relatively comparable. In addition, these three classes shared similar teaching content and progress, all taught by the same physics teacher using the same materials and pacing. Moreover, students were randomly assigned to the experimental groups to minimize potential differences in prior knowledge. All the students started learning physics as a compulsory subject in the 8th grade in middle school (approximately 13–14 years old). At the time the study was conducted, the knowledge content of the kinematics module had already been covered in the physics course. Each of the three groups completed three tasks in the same order. As

some abnormal and missing data were deleted, the final participant sample included 90 students (female = 47, male = 43), with 30 (female = 14, male = 16) in group A, 30 (female = 17, male = 13) in group B, and 30 (female = 16, male = 14) in group C.

C. Apparatus

In this study, the EYESO EX150 eye-tracking equipment was employed to capture and document eye movements, while a PC device was utilized for presenting materials. The eye-tracking equipment has a sampling rate of 150 Hz. It was connected to a 22-inch PC device with a resolution of 1920×1080 , securely positioned beneath the computer monitor for data acquisition. During the data collection phase, participants sat facing the monitor, granted freedom of head and eye movement, and interacted with tasks using a mouse and keyboard. The EYESO STUDIO software, installed on the PC device, was employed to record and analyze the eye-movement data.

D. Procedure

Each participant was required to attend the research individually. With the guidance of the researcher, the participants came to the room to complete the experiment. Before the formal testing stage, it took about 2 min for participants to familiarize themselves with the task and the procedure. Subsequently, the students were introduced to the eye-tracking device, and an initial eye-movement calibration was performed. This stage took only 1 or 2 min. The students who failed to complete the eye-movement calibration were excluded from further participation.

During the formal experiment, the participant was instructed to work on the physics problems presented on the screen. Each student needed to complete three items, with one item at a time shown on the screen. Participants completed each item by clicking a button with the mouse. There was no time limit for the participants in the formal experiment. The full experiment took between 20 and 30 min. Participants’ eye-movement data and question responses were recorded for further analysis. Besides, a screen recording software was used to record the screen during the experiment.

E. Data analysis

In this study, students’ performance scores and eye-movement behaviors were analyzed separately. Accuracy data were analyzed using a chi-square test to examine whether students’ performance differed across the three types of physics problems (information-explicit, information-redundant, and information-implicit).

For the eye-tracking data, AOIs were marked on each item. The distribution of AOIs is illustrated in Fig. 2. Two primary spatial regions were defined: the Text AOI

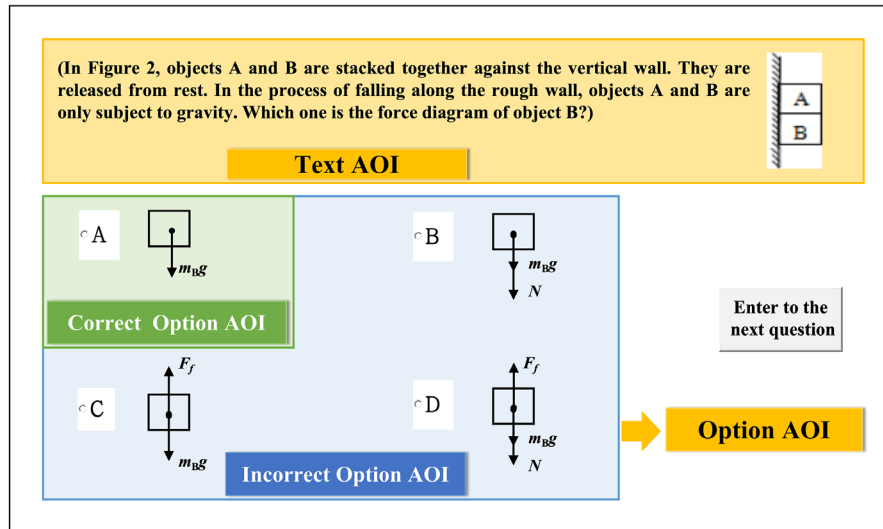


FIG. 2. An example (question 2) of the physics problems used in the test. A checkbox was provided next to each option, and a submit button was provided on the right side of the screen. The multiple-choice problems with two areas of interest were used in the experiment: text AOI and option AOI. During analysis, the option AOI was further divided into correct option AOI and incorrect option AOI.

(including the problem statement and accompanying diagram) and the option AOI (including the four answer choices). All AOIs were defined as mutually exclusive, with no overlapping regions. For analysis, the option AOI was further divided into the correct option AOI and the incorrect option AOI. The correct option AOI reflects the area of the single correct option, and the incorrect option AOI reflects the area of the other three incorrect options.

Accordingly, fixation time and revisits were calculated for four AOIs: text AOI, overall option AOI, correct option AOI, and incorrect option AOI. In addition, total fixation time was defined as the sum of the visit durations within each AOI. The number of revisits reflects how many times the participant's gaze returns to the previously viewed AOI from other AOIs. 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 150 Hz).

To examine how physics problems with different information structures influenced students' visual attention, we conducted Friedman tests on overall eye-movement indicators (i.e., total fixation time and total number of revisits) and eye-movement indicators within specific AOIs. The type of problems (information-explicit, information-implicit, and information-redundant physics problems) served as the independent variable. The dependent variables included total fixation time and revisit count, as well as

fixation time and the number of revisits within specific AOIs (i.e., text AOI, option AOI, correct option AOI, and incorrect option AOI). When significant effects were observed, Durbin-Conover *Post hoc* comparisons were used to further explore pairwise differences.

V. RESULT

A. Students' learning performance across three types of physics problems

Table I presents the descriptive statistics and the chi-square test results for students' accuracy across the three types of physics problems (information-explicit, information-redundant, and information-implicit) as well as across individual problem items. The descriptive data showed that students achieved the highest mean accuracy on information-explicit problems ($M = 0.46$, $SD = 0.50$), followed by information-redundant ($M = 0.37$, $SD = 0.48$) and information-implicit problems ($M = 0.36$, $SD = 0.48$). However, the chi-square test revealed no statistically significant differences in accuracy among the three problem types ($\chi^2 = 2.27$, d.o.f. = 2, $p = 0.322$, Cramér's $V = 0.16$). Similarly, no significant association was observed between accuracy and the three items ($\chi^2 = 1.71$, d.o.f. = 2, $p = 0.426$, Cramér's $V = 0.14$).

Further analyses examined the interaction between problem item (Q1–Q3) and information type. The results indicated that the interaction effect was not significant for Q1 ($\chi^2 = 1.15$, d.o.f. = 2, $p = 0.563$, Cramér's $V = 0.11$), Q2 ($\chi^2 = 0.71$, d.o.f. = 2, $p = 0.700$, Cramér's $V = 0.09$), or Q3 ($\chi^2 = 3.21$, d.o.f. = 2, $p = 0.200$, Cramér's $V = 0.19$). These findings suggested that neither the specific content of the physics problems nor the interaction between problem items and information

TABLE I. Chi-square test results for accuracy across problem items and information types.

Comparison	M	SD	χ^2	d.o.f.	p	Cramér's V
Information-explicit	0.46	0.50	—	—	—	—
Information-redundant	0.37	0.48	—	—	—	—
Information-implicit	0.36	0.48	—	—	—	—
Accuracy across three types of physics problems	—	—	2.27	2	0.322	0.16
Accuracy across three problem items (Q1–Q3)	—	—	1.71	2	0.426	0.14
Q1: Accuracy $\times$ Information type	—	—	1.15	2	0.563	0.11
Q2: Accuracy $\times$ Information type	—	—	0.71	2	0.700	0.09
Q3: Accuracy $\times$ Information type	—	—	3.21	2	0.200	0.19

structures significantly affected students' problem-solving accuracy. In other words, variations in information structures did not significantly impact students' achievement in solving the physics problems.

Students' responses revealed several common misconceptions. For question 1, some students incorrectly believed that the car represented by the top curve in the distance-time graph traveled a longer distance between time points t_1 and t_2 . In question 2, some students assumed that if object A had a greater mass than object B ($m_A > m_B$), it must exert a downward force on object B, rather than considering the actual state of motion to judge the forces involved. In question 3, when the motion state of the objects was not explicitly provided (e.g., "The sliders A and B are stacked together and move upward along the inclined plane in uniformly decelerated rectilinear motion"), students were expected to infer the forces based on context. However, many became confused by the description of the initial velocity (v_0) and incorrectly assumed that the net external force must be in the same direction as v_0 , leading them to select option D.

B. Students' fixation time across different AOIs

To explore possible differences in eye-movement behaviors among information-explicit, information-redundant, and information-implicit physics problems, the collected eye-movement data were compared in terms of fixation time, which reflects the degree of information processing. In addition, we calculated the mean eye fixation time

obtained for the three types of physics problems on text AOI, option AOI, correct option AOI, and incorrect option AOI, respectively (see Table II).

A Friedman test was first conducted on the total fixation time per item. As shown in Table III, the result indicated a significant difference across the three problem types ($\chi^2 = 22.40$, d.o.f. = 2, $p < 0.001$). Durbin-Conover post hoc tests further revealed that students spent significantly more time on information-redundant problems ($M = 69.68$ s, $SD = 17.93$) than on both information-explicit problems ($M = 59.97$, $SD = 23.53$, $p < 0.001$) and information-implicit problems ($M = 59.09$, $SD = 32.55$, $p < 0.001$).

In addition, a Friedman test was conducted to examine differences in fixation time on the text AOI. The result revealed a significant difference ($\chi^2 = 19.60$, d.o.f. = 2, $p < 0.001$), indicating that students' attention varied significantly across the three problem types. Post hoc comparisons showed that students spent significantly more time on the text AOI in information-redundant problems ($M = 44.99$ s, $SD = 13.67$) compared to both information-explicit ($M = 38.57$, $SD = 20.65$, $p < 0.001$) and information-implicit problems ($M = 35.39$, $SD = 24.30$, $p < 0.001$). Similarly, for the option AOI, the Friedman test also revealed a significant effect ($\chi^2 = 7.40$, d.o.f. = 2, $p = 0.025$). Students spent more time on options in information-redundant problems ($M = 24.69$, $SD = 9.52$) than in information-explicit ($M = 21.40$, $SD = 10.27$, $p = 0.013$) and information-implicit problems ($M = 23.70$, $SD = 16.70$, $p = 0.024$). While no

TABLE II. Descriptive statistics of total fixation time and fixation time across different AOIs for information-explicit, information-redundant, and information-implicit physics problems.

	Information-explicit ($n = 90$)		Information-redundant ($n = 90$)		Information-implicit ($n = 90$)	
	M	SD	M	SD	M	SD
Mean total fixation time per item (seconds)	59.97	23.53	69.68	17.93	59.09	32.55
Fixation time in (seconds)						
Text AOI	38.57	20.65	44.99	13.67	35.39	24.30
Option AOI	21.40	10.27	24.69	9.52	23.70	16.70
Correct option AOI	5.80	4.71	4.32	3.14	4.29	3.16
Incorrect option AOI	15.59	10.13	20.37	9.27	19.41	16.72

TABLE III. Friedman test results for total fixation time and fixation time across different AOIs (text, option, correct option, and incorrect option) in three types of physics problems. Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

		χ^2 (d.o.f. = 2)	p	Significant pairwise comparisons
Total fixation time		22.4	<0.001***	Redundant > Explicit ($p < 0.001$ ***) Redundant > Implicit ($p < 0.001$ ***)
Fixation time in	Text AOI	19.6	<0.001***	Redundant > Explicit ($p < 0.001$ ***) Redundant > Implicit ($p < 0.001$ ***)
	Option AOI	7.4	0.025*	Redundant > Explicit ($p = 0.013$ *) Redundant > Implicit ($p = 0.024$ *)
	Correct option AOI	7.34	0.025*	Explicit > Redundant ($p = 0.038$ *) Explicit > Implicit ($p = 0.010$ *)
	Incorrect option AOI	8.19	0.017*	Explicit < Redundant ($p = 0.004$ **) Explicit < Implicit ($p = 0.004$ **)

significant difference was observed between the information-explicit and information-implicit problems.

As for option AOI, we focused on the correct option AOI and the incorrect option AOI. The detailed Friedman test results are also presented in Table III, and the descriptive statistics are visualized in Table IV. For correct options, the results revealed that the fixation time also differed significantly across the three problem types ($\chi^2 = 7.34$, d.o.f. = 2, $p = 0.025$). *Post hoc* paired test showed that students' attention allocated to the correct option AOI for the information-explicit problem ($M = 5.80$, $SD = 4.71$) was significantly higher than that for the information-redundant problem ($M = 4.32$, $SD = 3.14$, $p = 0.038$) and information-implicit physics problem ($M = 4.29$, $SD = 3.16$, $p = 0.010$). However, the difference between the information-redundant and information-implicit problems was not significant.

For incorrect options, the Friedman test showed a significant effect ($\chi^2 = 8.19$, d.o.f. = 2, $p = 0.017$). Conversely, the pattern for fixation on the incorrect option AOI was reversed. Students spent less time on the incorrect option in the information-explicit problem ($M = 15.59$, $SD = 5.13$, $p = 0.004$) than they did in information-redundant ($M = 20.37$, $SD = 9.27$) and information-implicit physics problems ($M = 19.41$, $SD = 16.72$, $p = 0.004$). The results were also found to be statistically significant (see Fig. 3). However, the difference between

the information-redundant and information-implicit problems was not significant. There was no significant difference between the information-redundant and information-implicit problems.

C. Students' revisits across different AOIs

To further examine how students monitor and reprocess information, we analyzed the number of revisits across the same four AOIs. The Friedman test was used to compare the average number of revisits among the three types of problems. The average number of revisits was also calculated for four AOIs for the three types of physics problems (see Table IV).

We first analyzed the overall number of revisits per item. The Friedman test revealed significant differences among the three problem types ($\chi^2 = 18.72$, d.o.f. = 2, $p < 0.001$). Pairwise comparisons indicated that students generally revisited more frequently in information-implicit problems ($M = 22.31$, $SD = 9.83$) than in information-explicit ($M = 17.48$, $SD = 7.24$, $p < 0.001$) and information-redundant problems ($M = 19.65$, $SD = 8.11$, $p = 0.013$). However, no significant difference was observed between the information-explicit and information-redundant problems.

A more detailed analysis was then conducted by separating the text AOI and the option AOI. For the text AOI, the Friedman test showed a significant effect ($\chi^2 = 26.90$,

TABLE IV. Descriptive statistics of the total number of revisits and revisits across different AOIs for information-explicit, information-redundant, and information-implicit physics problems.

		Information-explicit ($n = 90$)		Information-redundant ($n = 90$)		Information-implicit ($n = 90$)	
		M	SD	M	SD	M	SD
Mean total revisits per item (times)		19.60	8.92	21.37	10.50	25.32	11.40
Revisits (time)	Text AOI	9.97	5.22	11.18	6.68	14.96	7.40
	Option AOI	9.63	6.48	10.19	7.38	10.37	6.15
	Correct option AOI	2.77	3.94	1.52	1.54	1.91	1.85
	Incorrect option AOI	6.87	4.63	8.67	7.11	8.46	5.13

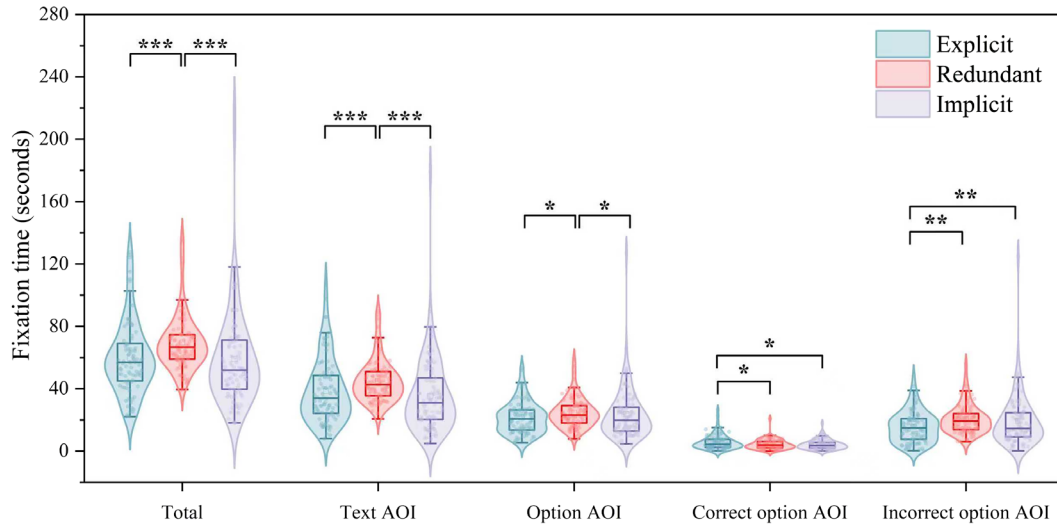


FIG. 3. Violin plots of fixation time in text AOI, option AOI, correct option AOI, and incorrect option AOI for information-explicit, information-redundant, and information-implicit physics problems. (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

d.o.f. = 2, $p < 0.001$). As illustrated in Fig. 4, students revisited the text more often in information-implicit problems ($M = 14.96$, $SD = 7.40$, $p < 0.001$) compared with both information-explicit ($M = 9.97$, $SD = 5.22$) and information-redundant problems ($M = 11.18$, $SD = 6.68$). In contrast, the test for option AOI indicated no significant difference across problem types ($\chi^2 = 1.77$, d.o.f. = 2, $p = 0.414$), suggesting that revisit behaviors to options were relatively stable regardless of how information was presented.

The number of revisits to the correct option differed significantly across problem types ($\chi^2 = 6.82$, d.o.f. = 2, $p = 0.033$). Further pairwise comparisons revealed that the correction option AOI in information-explicit problems

($M = 2.77$, $SD = 3.94$) obtains more revisits than that in information-redundant problems ($M = 1.52$, $SD = 1.53$, $p = 0.009$) and information-implicit problems ($M = 1.91$, $SD = 1.85$, $p = 0.039$). However, no significant difference was found between the information-redundant and information-implicit problems. For incorrect options, the Friedman test showed significant difference across problem types ($\chi^2 = 2.33$, d.o.f. = 2, $p = 0.035$). Conversely, the revisits of students in correction option AOI for the information-explicit problems ($M = 6.87$, $SD = 4.63$) were less frequent than for the information-redundant problems ($M = 8.67$, $SD = 7.11$, $p = 0.035$) and information-implicit problems ($M = 8.46$, $SD = 5.13$, $p = 0.049$). Again, the revisit frequency between the

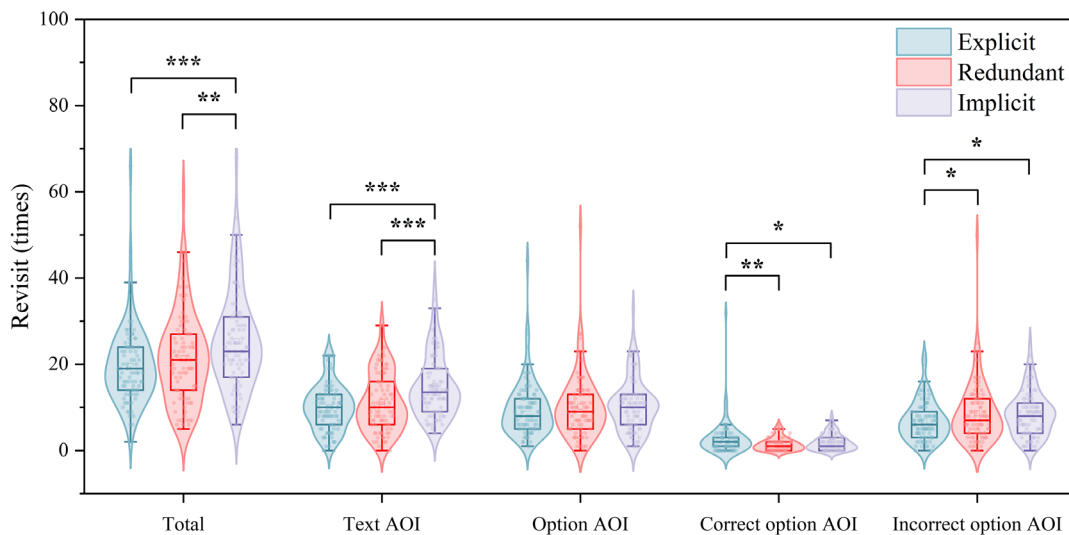


FIG. 4. Violin plots of revisits in text AOI, option AOI, correct option AOI, and incorrect option AOI for information-explicit, information-redundant, and information-implicit physics problems. (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

TABLE V. Friedman test results for total number of revisits and revisits across different AOIs (text, option, correct option, and incorrect option) in three types of physics problems. Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

		χ^2 (d.o.f. = 2)	p	Significant pairwise comparisons
Mean total revisits per item (times)		19.10	<0.001***	Implicit > Explicit ($p < 0.001$ ***) Implicit > Redundant ($p = 0.002$ **)
Revisits in	Text AOI	26.90	<0.001***	Implicit > Explicit ($p < 0.001$ ***) Implicit > Redundant ($p < 0.001$ ***)
	Option AOI	1.77	0.414	n.s.
	Correct option AOI	6.82	0.033*	Explicit > Redundant ($p = 0.009$ **) Explicit > Implicit ($p = 0.039$ *)
	Incorrect option AOI	4.33	0.035	Explicit < Redundant ($p = 0.049$ *) Explicit < Implicit ($p = 0.035$ *)

information-redundant and information-implicit problems did not significantly differ. The detailed Friedman test results for the total number of revisits and revisits across different AOIs are presented in Table V.

VI. DISCUSSION

In this study, we collected eye-movement data from 90 high school students while solving the three different types of physics problems, including information-explicit, information-redundant, and information-implicit physics problems. The study explored how physics problems with different information structures influence students' problem-solving processes. Specifically, we examined differences in students' performance and eye-movement behaviors across the three types of physics problems. Based on the result, it can be understood how different physics problems influence the students' information processing patterns.

A. Modest performance differences across physics problems with different information structures

Regarding the first research question, the results of the chi-square test revealed no differences in students' performance across the three types of physics problems. Although descriptive statistics showed that students achieved slightly higher accuracy on information-explicit problems ($M = 0.46$, $SD = 0.50$), followed by information-redundant ($M = 0.37$, $SD = 0.48$) and information-implicit problems ($M = 0.36$, $SD = 0.48$), these differences did not reach statistical significance. This finding suggested that the variation in information structures did not significantly influence students' problem-solving success at the outcome level. However, the slightly lower accuracy observed in the information-redundant and information-implicit problems might still reflect underlying cognitive processing challenges, which were further illuminated by the eye-tracking data.

Previous studies have reported that question type affects individuals' behaviors in representation selection and

integration [13–15]. In addition, the presence of extraneous information reduced the accuracy of students' solutions [36–42], and students might not handle insufficient problems successfully [33,76–78]. Our results partially supported these findings at the descriptive level, even though the performance differences were not statistically significant. From the work by van Merriënboer [16], it is suggested that learning to solve certain types of problems does not guarantee the mastery of competencies necessary to solve other types of problems. Therefore, research on the cognitive processes involved in solving a broader range of problem types remains important for fostering the development of student problem-solving competencies.

From an instructional perspective, teachers should not solely rely on outcome measures when designing problems. Although accuracy does not differ across problem types, different information structures may impose different cognitive demands on students. Therefore, educators should consider both correctness and cognitive efficiency when designing or selecting instructional materials.

B. Impact of physics problems with different information structures on students' visual attention

Regarding the second research question, we analyzed students' eye-movement behaviors, including fixation time and revisit, while solving physics problems with different information structures. The results of the eye-movement indexes showed that there were differences in students' eye-movement behaviors.

As for fixation time, students spent significantly more time fixating on information-redundant problems compared to the information-explicit and information-implicit physics problems, and the students fixated heavily on the text AOI. The extended fixation time suggested that the presence of extraneous information increased the cognitive load, compelling students to engage in more effortful processing to distinguish and compare relevant and irrelevant information. This trend was also observed in the option AOI, where students exhibited increased fixation duration when dealing with information-redundant

problems. This indicated that the additional information in the question text might have complicated the decision-making process, prompting students to spend more time repeatedly checking the options in search of matching or contradictory cues. Consistent with previous research, students could be challenged by the presence of irrelevant information in problems [42,79–81]. And previous studies pointed out that the semantically more complex the word was in the problem, the more time was required for information processing [60,61]. Another study reported that students required more integration time to solve extraneous information problems than necessary information problems [82].

In the option areas, students showed distinct gaze patterns depending on the problem type. For information-explicit problems, students fixated significantly longer on the correct options, aligning with the slightly higher accuracy observed in these problems. This suggested that students were better able to identify and confirm the correct answer due to the clarity of relevant information. In contrast, in information-redundant and information-implicit problems, students directed more attention toward incorrect options. This might indicate a degree of uncertainty or confusion among students, suggesting that students allocated additional cognitive effort to discriminating among the options when the problem statement contained unclear or misleading elements.

For the revisit behaviors, students displayed more revisits to the text AOI for the information-implicit physics problems than for the information-explicit and information-redundant ones. It can be inferred that students were repeatedly searching for hidden or implied information in the text AOI when they completed information-implicit physics problems. Students needed to extract and process repeatedly and frequently some obscure information that is not explicitly represented in the problem to solve problems successfully. Instead, those solving information-explicit problems reported fewer revisits to the text AOI, as they could access direct and effective information from the problems. It can be seen that the problem with different information causes discrepancies in the processing of visual information. In other words, the students might have recognized that information is obscure in the information-implicit problem and were actively seeking to process the relevant information for a solution.

Furthermore, the students frequently revisited the correct option for information-explicit problems. Conversely, their revisits to incorrect options in the information-redundant and information-implicit physics problems were more frequent than in the information-explicit problems. In the process of answering the information-redundant and information-implicit physics problems, students tended to pay more attention to comparing information among incorrect options. It reflected that redundant or implicit information distracted students when solving the problems with

sufficient information, and they approached the problem more cautiously and carefully.

Overall, the findings suggested that students adapt their visual attention and cognitive strategies based on the structure and clarity of the problem. The presence of redundant or implicit information tends to increase cognitive demands, leading to more prolonged fixations, more distributed attention, and more frequent revisits. In contrast, clear and explicit problems supported more focused attention and efficient decision making. These differences provided insights into how students navigate complex problem situations beyond correctness alone and highlight the importance of problem design in supporting effective learning and reasoning.

These findings also provide insights for physics instruction and the design of problem-based learning materials. First, the prolonged fixation time observed in information-redundant problems indicates that potentially distracting information might increase extraneous cognitive load. Although additional information is sometimes intended to clarify concepts, unnecessary details may obscure essential elements and lead to inefficient attention allocation. In multimedia problem design, teachers should consider whether added text supports understanding or increases cognitive load. Moreover, the increased revisits observed in information-implicit problems suggested that such tasks require students to infer and integrate information that is not explicitly stated. Although these problems may initially impose higher cognitive demands, they also provide opportunities to develop reasoning. Rather than avoiding information-implicit problems, instructors may consider beginning with information-explicit formats to establish foundational understanding and gradually introduce information-implicit tasks to challenge students' deeper reasoning. In addition, teachers can teach strategies for identifying key cues, filtering irrelevant information, and monitoring attention during problem solving.

VII. CONCLUSIONS AND IMPLICATIONS

The purpose of this study was to explore how physics problems with different information structures influence students' performance and visual attention. The eye-tracking technology was applied to detect the differences in students' eye-movement behaviors in solving physics problems with different information structures, including information-explicit, information-redundant, and information-implicit. Our findings indicated that there were significant differences when students processed the three types of physics problems. While students' overall accuracy did not differ significantly across the three problem types, their eye-movement behaviors revealed distinct cognitive strategies and challenges associated with different information structures.

For information-explicit problems, students spent more time fixating on the correct option AOI, suggesting efficient

identification of relevant information. In contrast, information-redundant problems prompted longer fixation time in both text and option areas. The presence of extraneous information increased cognitive load, as students needed to discriminate between relevant and irrelevant content. This aligns with cognitive load theory, which posits that irrelevant details can hinder processing efficiency and impede learning. Moreover, information-implicit problems elicited more frequent revisits to the text and incorrect options. This pattern indicated that students engaged in repeated scanning to uncover hidden cues or construct missing links. Such problems appear to challenge students' reasoning and integration skills, even if they do not lead to lower accuracy rates.

The implication can be derived from the findings of this study. Initially, considering the significance of recognizing and processing relevant information for successful problem solving, it is important to practice the ability to differentiate pertinent details from misleading information while engaging in the problem-solving process. The effort could foster students' sensitivity toward scientific concepts and help prevent misconceptions. For example, it could be beneficial for educators to instruct students to explicitly identify and mark key information on their own when tackling problems. Second, the findings highlight the importance of cultivating students' ability to draw inferences. Since solving information-implicit problems requires students to integrate multiple concepts and interpret incomplete information, students should be provided with more opportunities to practice reasoning under uncertainty. These skills are essential competencies for solving open-ended or real-world problems. In addition, teachers need to focus on developing students' ability to solve multiple types of physics problems, not merely the information-explicit problems. Third, this study suggested that employing modern technologies in educational research, such as eye tracking, holds significant value for exploring cognitive processing during problem solving and science learning. Insights derived from these studies could offer concrete guidelines on enhancing instructional methods to foster students' problem-solving skills.

Some limitations can be found in the present study. First, there was no pretest in the research design to assess

students' accurate prior knowledge of physics. Although all participants had completed the same instructional module and were randomly assigned to groups from classes of similar academic levels, it is still possible that individual differences in prior understanding may have influenced the results. Future research should incorporate a pretest or adopt a within-subjects design to control for individual differences. Second, the physics problems used in the present study were derived from three items selected from the Chinese National College Entrance Examination. The number of problems was limited, and the problems were drawn from the mechanics domain. Future research should include a larger set of physics problems covering a broader range of content areas and difficulty levels to enhance the generalizability of the findings. Moreover, the number of research participants is relatively limited, and the conclusions of the study can only be established based on the participants under investigation. Future research could be improved by investigating a more diverse pool of participants. Besides, an interview could be supplemented to confirm students' actual thoughts to improve the validity of the research.

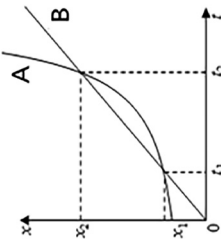
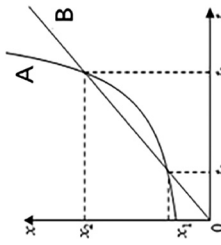
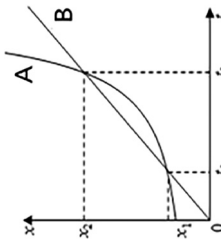
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DATA AVAILABILITY

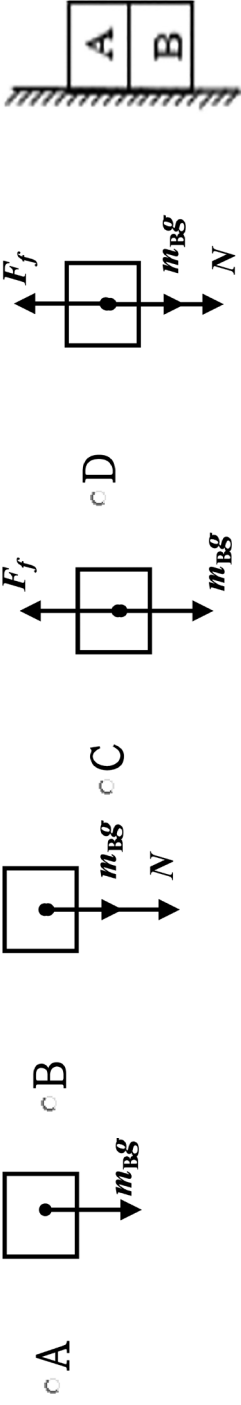
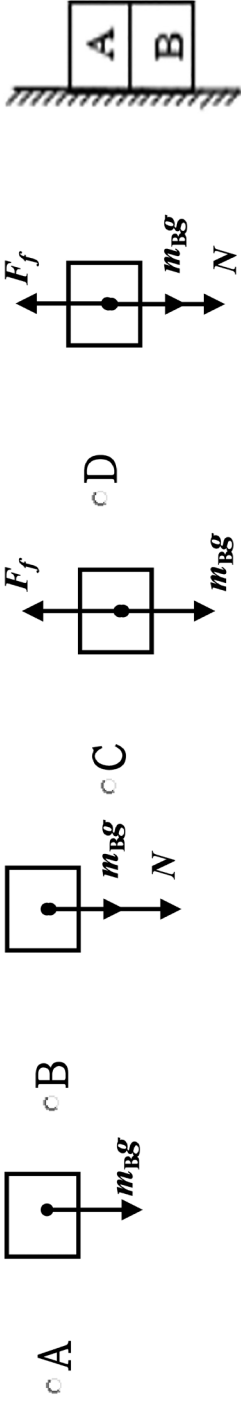
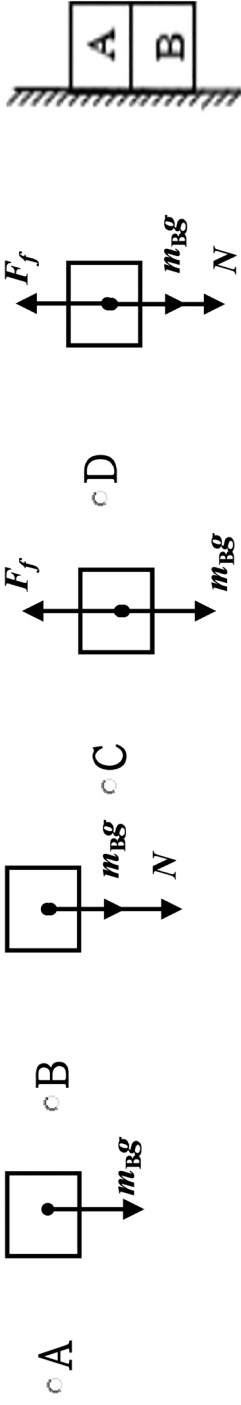
The data that support the findings of this article are not publicly available because they contain sensitive personal information. The data are available from the authors upon reasonable request.

APPENDIX

Question 1	Information-explicit	1. Car A and Car B are moving in the same direction on a straight road. Car A is moving uniformly accelerated in a straight line and Car B is moving uniformly in a straight line. The position-time ($x-t$) graph for both cars is shown in the accompanying graph. Which of the following statements is correct? () A. At the time t_1, the two cars have the same speed. B. The distances traveled by both cars from time 0 to t_1 are equal. C. From t_1 to t_2, Car B travels a greater distance than Car A. D. At some moment between t_1 and t_2, the two cars have the same speed.	
	Information-redundant	1. Car A and Car B are moving in the same direction on a straight road. Car A is moving uniformly accelerated in a straight line and Car B is moving uniformly in a straight line. The position-time ($x-t$) graph for both cars is shown in the accompanying graph. The curve representing displacement of car B is above that of car A between t_1 and t_2. Which of the following statements is correct? () A. At the time t_1, the two cars have the same speed. B. The distances traveled by both cars from time 0 to t_1 are equal. C. From t_1 to t_2, Car B travels a greater distance than Car A. D. At some moment between t_1 and t_2, the two cars have the same speed.	
	Information-implicit	1. Car A and Car B are moving in the same direction on a straight road. The position-time ($x-t$) graph for both cars is shown in the accompanying graph. Which of the following statements is correct? () (Delete: "Car A moving uniformly accelerated in a straight line and car B moving uniformly in a straight line.") A. At the time t_1, the two cars have the same speed. B. The distances traveled by both cars from time 0 to t_1 are equal. C. From t_1 to t_2, Car B travels a greater distance than Car A. D. At some moment between t_1 and t_2, the two cars have the same speed.	

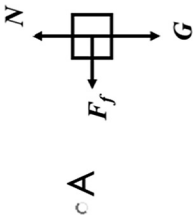
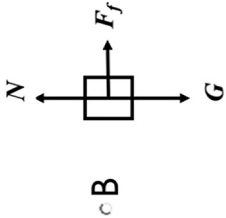
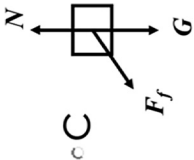
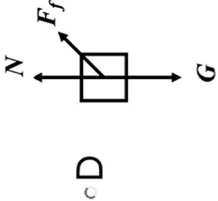
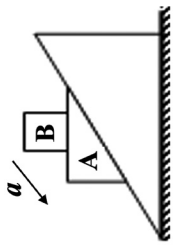
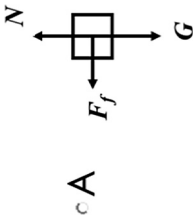
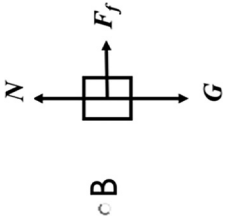
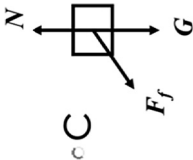
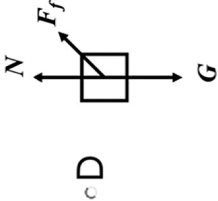
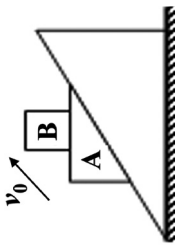
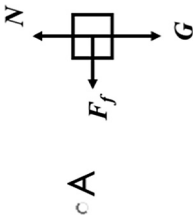
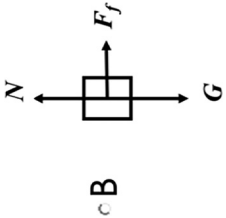
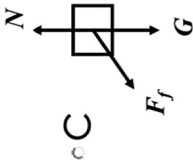
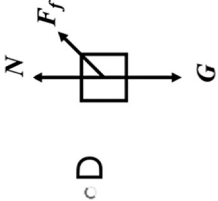
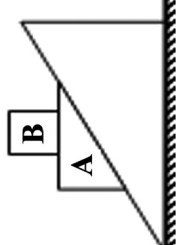
(Table continued)

(Continued)

Question 2	Information-explicit	2. In the diagram, objects A and B are stacked together against the vertical wall. They are released from rest. In the process of falling along the rough wall, objects A and B as a whole are only subject to gravity. Which of the following diagrams correctly shows the forces acting on object B? () 
	Information-redundant	Note: F_f represents frictional force. 2. In the diagram, objects A and B are stacked together against the vertical wall, and $m_A > m_B$ (mass). They are released from rest. In the process of falling along the rough wall, objects A and B are as a whole only subject to gravity. Which of the following diagrams correctly shows the forces acting on object B? () 
	Information-implicit	Note: F_f represents frictional force. 2. In the diagram, objects A and B are stacked together against the vertical wall. They are released from rest. In the process of falling along the rough wall, objects A and B as a whole are only subject to gravity." (Delete: "objects A and B as a whole are only subject to gravity.") 

(Table continued)

(Continued)

Question 3	Information-explicit	3. As shown in the diagram, the smooth inclined surface is fixed on the horizontal plane. The sliders A and B are stacked together and move upward along the inclined plane in uniformly decelerated rectilinear motion. The sliders A and B always remain relatively static, and the upper surface of A is horizontal. When the sliders A and B are moving on the inclined plane, which of the following diagrams correctly shows the forces acting on slider B?     
	Information-redundant	Note: F_f represents frictional force. 3. As shown below, the smooth inclined surface is fixed on the horizontal plane. The sliders A and B are stacked together and move upward with the initial speed of v_0 along the inclined plane in uniformly decelerated rectilinear motion. The sliders A and B always remain relatively static, and the upper surface of A is horizontal. When the sliders A and B are moving on the inclined plane, which of the following diagrams correctly shows the forces acting on slider B?     
	Information-implicit	Note: F_f represents frictional force. 3. As shown below, the smooth inclined surface is fixed on the horizontal plane. The sliders A and B are stacked together and move upward along the inclined plane. The sliders A and B always remain relatively static, and the upper surface of A is horizontal. When the sliders A and B are moving on the inclined plane, which of the following diagrams correctly shows the forces acting on slider B? (Delete: “in uniformly decelerated rectilinear motion.”)     

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