



Prompting self-explanation in different gameplay contexts: effects on response quality and content learning

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Abstract

Asking students to self-explain their in-game actions using targeted content knowledge can support reflection and enhance learning in educational games. However, in the highly engaging and performance-focused context of educational games, it remains unclear how such prompts can be designed and embedded in gameplay to ensure that learners meaningfully respond to them. This study examines how self-explanation prompts embedded in different prompting contexts—integrated within ongoing gameplay or positioned as a separate reflective activity after gameplay—influence students' response quality and content learning. A pretest–posttest experiment was conducted with 92 high school students randomly assigned to one of three conditions while playing a physics game: (1) receiving prompts during gameplay; (2) receiving the same prompts after gameplay; or (3) receiving no prompts. Prompts were delivered as on-screen messages asking students to explain how they solved game levels using targeted physics concepts. Qualitative data from classroom observations and student interviews were used to interpret the findings. Results showed that students who received self-explanation prompts demonstrated significantly greater learning gains than those who did not. Moreover, prompts delivered during and after gameplay yielded similar response quality, whereas prompts delivered during gameplay led to greater learning gains than those delivered after gameplay. These findings suggest that different prompting contexts involve distinct mechanisms for supporting learner engagement, rather than representing a simple difference in timing. The study provides implications for designing self-explanation prompts to support meaningful learner responses and, in turn, improve learning in educational games across these prompting contexts.

Keywords Game-based learning · Self-explanation · Prompting context · Learner engagement · Reflection-in-action · Reflection-on-action

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Introduction

Educational games—video games designed for learning—are increasingly recognized as engaging and powerful learning tools (Gee, 2005; Ivgin & Akcay, 2024; Shaheen et al., 2023; Shute, et al., 2021; Squire, 2005). Unlike traditional lecture-based instruction, where subject content is delivered explicitly, game-based learning embeds content implicitly within gameplay mechanics, fostering experiential learning through immersive problem-solving (Alotaibi, 2024; Barab et al., 2009; Chen & Chang, 2024; Miller et al., 2024).

However, empirical evidence indicates that despite high gameplay engagement, students may rely on trial-and-error strategies and fail to connect their in-game actions to underlying subject knowledge (Bacalja, 2024; Pan et al., 2024; Shaheen et al., 2023; Squire & Jan, 2007). Without deliberate reflection linking game problem-solving to subject content, game engagement may not translate into explicit or transferable learning (Bacalja, 2024; Barab et al., 2009; Chen & Chang, 2024; Miller et al., 2024; Pan et al., 2024; Yang et al., 2021).

A promising strategy to bridge this gap involves prompting students to self-explain their gameplay actions using subject concepts and principles (Bisra et al., 2018; Chi, 2021; Roy & Chi, 2005). Self-explanation—a domain-general metacognitive strategy where learners generate inferences and articulate reasoning to deepen understanding—has demonstrated significant learning benefits across diverse contexts, known as the self-explanation effect (Chen et al., 2025; Chi, 2021; Li et al., 2024; Roy & Chi, 2005; Wang & Xu, 2024).

Researchers have begun exploring whether this effect extends to game-based environments (e.g., Adams & Clark, 2014; Chiou et al., 2025; Clark et al., 2016; Killingsworth et al., 2015; McLaren et al., 2022). Typically, prior studies implemented self-explanation prompts as mandatory multiple-choice questions triggered by specific in-game events (Baker et al., 2024; Chiou et al., 2025; Clark et al., 2016; Killingsworth et al., 2015; Nguyen et al., 2023). This approach creates a fundamental tension: self-explanation requires deliberate reflection to connect game actions to subject knowledge, while gameplay inherently rewards quick decision-making and continuous progression toward goals. Consequently, students tend to perceive such prompts delivered during gameplay as obstacles to bypass rather than opportunities for reflection, leading to low-quality explanations and limited learning benefits (Adams & Clark, 2014; Beege & Ploetzner, 2025; Chiou et al., 2025; Fukuda et al., 2024; Nguyen et al., 2023).

To address this limitation, the present study examines an optimized self-explanation prompting intervention in an educational game. Because prior research suggests that reflective prompts may compete with the goals and flow of gameplay, how prompts are positioned in relation to gameplay becomes an important design issue. Specifically, prompts were designed to be voluntary rather than mandatory and open-ended rather than menu-based, and the study compares two prompting contexts that differ in how self-explanation is positioned relative to gameplay: prompts are presented either during gameplay, embedded within ongoing problem-solving processes, or after gameplay, where they are positioned as separate reflective activities. Using a physics learning game, *Save Kitten*, this study compares gameplay without prompts to two self-explanation prompting contexts and examines both students' self-explanation quality and content learning outcomes. Self-explanation quality was examined because it captures the extent to which students engaged in the reflective process targeted by the prompts, whereas content learning reflects the distal learning outcome of that process. The study aims to advance understanding of how prompting contexts shape students' engagement with self-explanation prompts, as well

as their reflective processes and learning in educational games. It contributes to ongoing efforts to leverage self-explanation to support student reflection and learning in game-based environments.

Background

The role of reflection in game-based learning

Educational games are widely recognized as promising learning tools that can offer engaging and active learning experiences (Gee, 2005; Ivgin & Akcay, 2024; Shaheen et al., 2023; Shute et al., 2021; Squire, 2005). Students often begin by solving game problems using trial-and-error strategies; they then form preliminary hypotheses about game mechanics and underlying content by reflecting on in-game feedback, followed by testing and refining these hypotheses in subsequent rounds of gameplay (Ho et al., 2022; Kiili, 2005). Such a game-based experiential learning process can lead students to master both game problem-solving and the targeted content (Alf et al., 2023; Chen & Chang, 2024; Kiili, 2005; Shaheen et al., 2023).

However, this learning process is unlikely to occur without additional instructional support (Alf et al., 2023; Bacalja, 2024; Chen & Chang, 2024; Pan et al., 2024; Shaheen et al., 2023). Students may continue relying on trial-and-error strategies without consciously reflecting on their game actions or linking them to embedded, domain-specific knowledge (Chen & Chang, 2024; Pan et al., 2024; Shaheen et al., 2023; Squire & Jan, 2007; Yang et al., 2021). For instance, Chen and Chang (2024) reported that some middle school students exhibited shallow learning behaviors, such as guessing or repeating failed actions, when playing a science learning game independently. The researchers explained that, when playing independently, students often become absorbed in the entertainment aspects of the game and lose sight of its educational objectives, failing to connect gameplay to underlying scientific concepts. Similarly, Barab et al. (2009) found that many students played a science educational game without explicitly recognizing the scientific principles involved, leading to fragmented or flawed conceptual understanding. Thus, examining how to promote reflection—particularly how to facilitate connections between gameplay and underlying content—is critical for translating gameplay engagement into meaningful content learning (Barab et al., 2009; Chen & Chang, 2024; Miller et al., 2024; Shaheen et al., 2023; Yang et al., 2021).

Reflection support in game-based learning contexts can be implemented through in-game features (e.g., on-screen prompts) or instructor-led guidance (e.g., debriefing; Yang & Liu, 2021). This study focuses on in-game reflection support, specifically self-explanation prompts that ask students to explain their game actions by connecting them to underlying content.

Prompting self-explanation in game-based learning

Self-explanation is a metacognitive strategy in which learners generate explanations for themselves to deepen their understanding of newly encountered material and make it personally meaningful (Chi, 2021; Roy & Chi, 2005). The self-explanation effect—where students learn better when they self-explain compared to when they do not—has been verified across various content domains, educational levels, and learning contexts such as reading,

worked examples, simulations, video-based instruction, and computer-based tutoring systems (Bisra et al., 2018; Chen et al., 2025; Li et al., 2024; Wang & Xu, 2024). Importantly, the learning benefits of self-explanation depend on learners' generative effort to produce meaningful explanations rather than on the mere presence of prompts (Chi, 2021; Roy & Chi, 2005). Thus, in game-based learning, self-explanation quality is an important proximal outcome because it reflects the extent to which students connect their gameplay actions to underlying subject principles.

However, when extending the self-explanation effect to educational game environments, the literature reports a fundamental challenge in prompting high-quality self-explanation: students may disregard prompts delivered during gameplay, resulting in superficial responses (Adams & Clark, 2014; Beege & Ploetzner, 2025; Chiou et al., 2025; Fukuda et al., 2024; Nguyen et al., 2023). For example, Nguyen et al. (2023) embedded multiple-choice self-explanation prompts between levels of a digital math game asking students to reflect on their gameplay by linking it to relevant subject concepts (e.g., "Explain why you chose 0.5 as the largest decimal. What strategy did you use?"). However, many students were found to exhibit gaming behaviors in response—such as rapidly clicking through options or selecting answers at random to advance—ultimately undermining the intended learning benefits (Baker et al., 2024; Nguyen et al., 2023). Another example is provided by Alf et al. (2023), who asked student teams to answer open-ended reflective questions, such as "What went well?" and "What did not go well?" several times while playing a simulation game. The researchers reported that some teams repeatedly gave broad and shallow answers to these prompts, typing statements like "We did well in the game" and "We need to improve."

The issue of low-quality self-explanation in game-based learning can be attributed to two main causes. First, students are primarily motivated to win or progress in the game, therefore, they may view self-explanation as a separate academic task that interferes with the fun or flow of gameplay (Adams & Clark, 2014; Beege & Ploetzner, 2025; Chiou et al., 2025; Csikszentmihalyi, 1975; Gee, 2005). Second, self-explanation is cognitively demanding because it requires activating relevant prior knowledge and integrating new information into coherent understanding (Chi, 2021). At the same time, unstructured in-game problem-solving also imposes a heavy cognitive load, leaving limited resources for high-quality self-explanation (Fukuda et al., 2024). Given these motivational tensions and cognitive load demands, students may be unwilling or unable to allocate the necessary cognitive effort while immersed in gameplay.

One way to address this challenge is to optimize prompt design. First, the present study adopted a voluntary rather than mandatory design. Prior studies often implemented in-game self-explanation prompts as mandatory, requiring students to respond—sometimes correctly—before resuming play (Baker et al., 2024; Chiou et al., 2025; Clark et al., 2016; Killingsworth et al., 2015; Nguyen et al., 2023). However, according to self-determination theory, supporting learners' autonomy is important for sustaining intrinsic motivation (Ryan & Deci, 2020). In contrast, a voluntary design may better support learners' autonomy and increase the likelihood that they engage with self-explanation as a meaningful learning activity rather than as an interruption to gameplay.

Second, the present study adopted an open-ended rather than menu-based design. This decision was grounded in the self-explanation principle, which conceptualizes effective self-explanation as a constructive and generative process rather than simple response selection (Chi, 2021; Roy & Chi, 2005). In game-based contexts, highly constrained response formats may encourage superficial responding, as learners can advance by selecting or guessing among options (Baker et al., 2024; Chiou et al., 2025;

McLaren et al., 2022; Nguyen et al., 2023). Furthermore, overly broad reflective questions may still elicit vague or superficial responses (Alf et al., 2023). The present study therefore employed open-ended prompts that asked students to explain their game actions using the target physics principles, thereby preserving the generative nature of self-explanation while keeping learners' attention focused on the disciplinary knowledge embedded in gameplay.

Beyond prompt format itself, a more central design question concerns how self-explanation should be situated in relation to gameplay. From a game-based learning perspective, educational games engage students through goal-directed problem solving, feedback, and progression (Gee, 2005; Kiili, 2005). Therefore, the timing of self-explanation prompts matters because it helps define the context in which students encounter and respond to the prompts: prompts delivered during gameplay are embedded within the ongoing problem-solving context of the game, whereas prompts delivered after gameplay are positioned as a separate reflective activity outside the immediate gameplay process. Most prior studies have embedded self-explanation prompts during gameplay, where learners may disregard the prompts because their attention and effort are primarily directed toward solving immediate game problems and progressing through the game (Adams & Clark, 2014; Baker et al., 2024; Chiou et al., 2025; Clark et al., 2016; Killingsworth et al., 2015; Nguyen et al., 2023). These attentional, motivational, and cognitive challenges raise the question of whether embedding prompts within ongoing gameplay is always optimal for supporting reflective engagement. One alternative is to delay self-explanation prompts until after the entire gameplay session, thereby positioning self-explanation not as an activity embedded within ongoing problem solving, but as a standalone reflective task.

Delaying self-explanation prompts to support reflection-on-action

Delaying prompts until after the entire gameplay session is aligned with Schön's (1983) concept of reflection-on-action, which refers to retrospective reflection after an activity has been completed. In contrast to reflection-in-action, which occurs during ongoing activity, reflection-on-action allows learners to step back from immediate task demands, revisit what they did, and more deliberately analyze the principles underlying their prior decisions (Munby, 1989; Schön, 1983). In the context of educational gameplay, this may be particularly valuable because learners are no longer occupied with the immediate demands of passing levels or achieving in-game goals and may therefore be better positioned to reconstruct their game actions and connect them to disciplinary concepts.

This rationale is also consistent with post-game debriefing practices in game-based pedagogy, where reflection is often deliberately positioned after gameplay to support meaning-making and conceptual integration (Bado, 2022; Baßeng & Budke, 2025; Zhang & Hu, 2024). When educational games are used in classroom settings, teachers often organize whole-class or small-group discussions to help students make explicit connections between their gameplay experiences and underlying content knowledge (Bado, 2022). Such debriefing can shift students' focus from game performance to academic content and facilitate more explicit and transferable learning from gameplay (Baßeng & Budke, 2025; Yang & Liu, 2021; Zhang & Hu, 2024). Yet, while prior work has primarily examined teacher-guided or socially supported forms of post-game reflection, it remains unclear whether self-explanation prompts delivered as on-screen messages after the completion of gameplay can effectively serve a similar reflective function.

Research questions and hypotheses

This study examined the effectiveness of prompting self-explanation in game-based learning and compared two prompting contexts—during gameplay and after gameplay—in terms of students' response quality and content learning. Specifically, the research questions and hypotheses based on the above rationale are shown below:

RQ1 Is prompting self-explanation effective in improving students' content learning in educational games compared to no prompting?

RQ2 Which prompting context—during gameplay or after gameplay—leads to higher self-explanation quality?

RQ3 Which prompting context—during gameplay or after gameplay—is more effective in improving content learning?

H1 Students who receive self-explanation prompts will demonstrate greater content learning than students who play the game without prompts.

H2 Students in the after-gameplay condition will produce higher-quality self-explanations than students in the during-gameplay condition.

H3 Students in the after-gameplay condition will demonstrate greater content learning than students in the during-gameplay condition.

Materials and methods

Research design and participants

This study employed an experimental design to examine the effects of self-explanation prompting and prompting context on students' self-explanation quality and content learning in educational games. Qualitative data, collected through gameplay observations and brief student interviews, were used as a complementary source of evidence to help interpret the quantitative findings. The study was conducted as part of a regular high school information technology course in a computer lab and was centered on a physics learning unit on force composition, which students had already learned in their regular physics classes. The information technology course was selected because access to computer lab facilities was limited to this context within the school.

A total of 110 tenth-grade students were recruited from a large public high school in southern China. After excluding 18 students due to incomplete pretest or posttest data, the final sample included 92 students ($M_{age}=15.55$, $SD=.54$, $Min=14$, $Max=17$; 65% female, 35% male).

Participants were individually randomly assigned to one of three experimental conditions to play a physics educational game *Save Kitten* for 35 min. Random assignment was implemented by providing each student with a specific URL corresponding to a preconfigured version of the game, with each version representing one experimental

condition. In the During condition ($n=37$), students played the game with self-explanation prompts delivered between game levels; in the After condition ($n=35$), the prompts were presented after students completed the entire gameplay session. In the Control condition ($n=20$), students played without any prompts. While the two prompting conditions differ in when prompts are presented, the key distinction lies in how prompting is embedded relative to gameplay—either integrated within ongoing gameplay or separated from gameplay as a reflective activity. The unequal group sizes in the final sample resulted from post hoc exclusion of participants with incomplete data rather than from unequal assignment at the outset. Comparisons across the three groups on gender, age, and physics pretest scores revealed no significant differences, confirming baseline equivalence.

The prompts took the form of open-ended, voluntary textual messages presented within the game, asking students to explain their game solutions using targeted physics knowledge, specifically by drawing force diagrams on printed screenshots of relevant game levels provided in a handout.

The game *Save Kitten*

Save Kitten is a two-dimensional web-based physics educational game designed to help secondary school students learn the Newtonian principle of force composition, which involves determining the net force generated by multiple concurrent forces acting on an object using the parallelogram method. The game was designed in alignment with the game flow framework (Kiili & Lainema, 2008) and underwent usability testing to confirm its functionality and user-friendliness prior to this study.

The game consists of 13 levels, each aiming to save a kitten floating on a balloon by directing a falling ball toward it. Players control the ball by dragging and dropping arrows from the left panel onto the ball, where each arrow's direction and length represent the direction and magnitude of an external force. Initially, the ball falls due to gravity. Once an arrow is released, the ball moves in the direction of the net force, calculated using the parallelogram method to combine gravitational and external forces. A brief tutorial at the beginning introduces the game's objectives and mechanics, and a menu is accessible throughout gameplay, allowing players to jump to any level. In Levels 1–10, players apply a single external force. From Level 11 onward, students must apply two sequential external forces to navigate around barriers and reach the balloon (see Fig. 1).

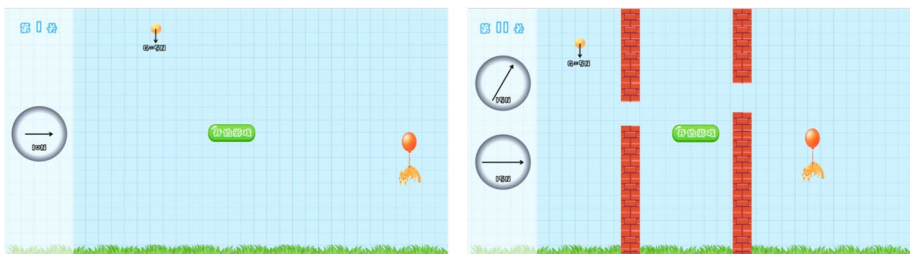


Fig. 1 Level 1 (left) and Level 11 (right)

The three conditions

The during condition

In the During condition, students received five self-explanation prompts delivered after completing the last five levels (Levels 9–13) during their first attempt, regardless of success or failure. These prompts were not shown during repeated attempts of the same level. To clarify, one prompt was delivered after students completed Level 9, another after Level 10, and so on, through Level 13. The decision to focus on the last five levels was made to ensure consistency across conditions, as both the During and After conditions required students to self-explain the same set of levels. By prioritizing recent gameplay experiences (Levels 9–13), the design reduced cognitive load associated with recalling earlier levels in the After condition and helped maintain the validity of comparisons between conditions.

For each prompt, students were asked to self-explain how they solved or planned to solve specific levels using their understanding of force composition, by drawing force diagrams on a handout (see Fig. 2). The prompts emphasized the instrumental value of self-explanation for improving gameplay performance: “Doing so helps you solve the following levels.” This framing was intended to reduce the motivational tension between self-explaining and gameplay. Students could resume gameplay without responding by clicking the “Continue” button at the bottom of the prompt page.

The after condition

In the After condition, students engaged in 30 min of uninterrupted gameplay, followed by a five-minute self-explanation session in which they were asked to draw force diagrams on the handout to explain their solutions for the last five levels—the same amount of prompting as the During condition. The duration of this session was based on usability testing, which indicated that self-explaining each level required approximately one minute. A text box on the game’s home screen described this procedure at the start of gameplay.

After the 30-min gameplay phase, a self-explanation prompt page (see Fig. 3) was displayed. To shift students’ focus from gameplay to content learning, the prompt emphasized the pedagogical value of self-explanation for physics learning: “This will help you learn physics better.” A “Menu” button at the bottom of the prompt page allowed students to revisit any level to refresh their gameplay memories—a feature designed to address the possibility that they may have forgotten how they solved the levels by the end of gameplay.

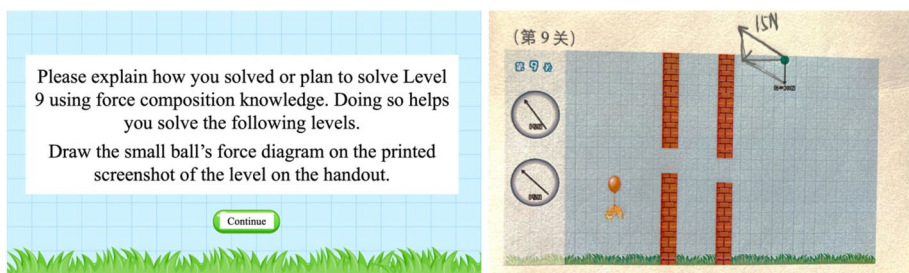


Fig. 2 Example prompt page from Level 9 in the during condition (left; original Chinese text translated into English), and a student’s written self-explanation example (right)

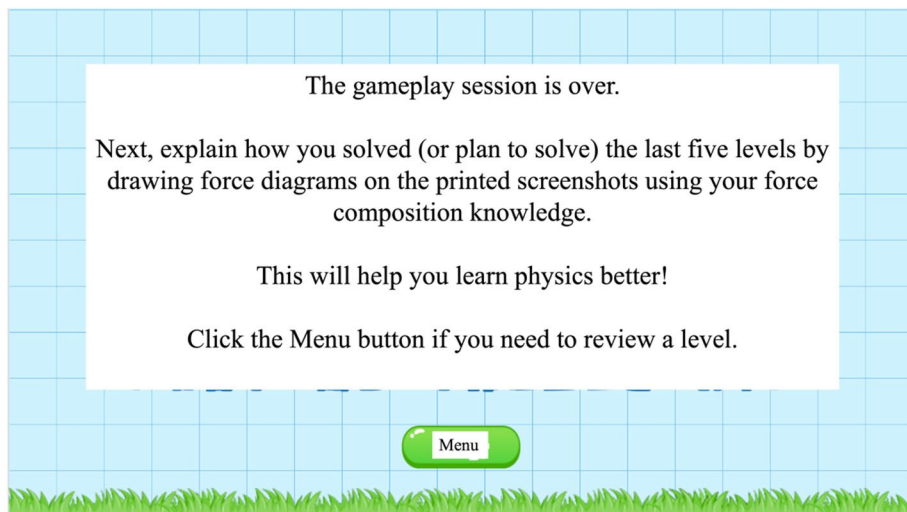


Fig. 3 The prompt page in the After condition (original Chinese text translated into English)

The control condition

Students in the Control condition played the game without receiving any self-explanation prompts. They experienced all standard game features, including the tutorial and all 13 levels. Upon successfully completing all levels, a “Congratulations” screen (see Fig. 4) was displayed, encouraging students to replay the game and explore alternative solutions until the 35-min gameplay session ended.



Fig. 4 The “Congratulations” page in the control condition (original Chinese text translated into English)

Measures

Physics knowledge test

To measure students' understanding of force composition before and after the study, two isomorphic test forms (Form A and Form B) were developed with the assistance of a content expert. Each form consisted of nine multiple-choice questions (see Fig. 5), with each question scoring one point. The forms were counterbalanced (Ryan & Brockmann, 2009), meaning students who received Form A for the pretest received Form B for the posttest, and vice versa. Both forms demonstrated acceptable internal reliability, with Cronbach's $\alpha = 0.74$ for Form A and 0.62 for Form B.

Although the forms were designed to be parallel, minor differences in difficulty were observed: pretest scores for Form A ($M = 6.69$, $SD = 1.76$) were significantly higher than those for Form B ($M = 4.46$, $SD = 1.94$), $t(90) = 5.76$, $p < .001$. To address this discrepancy, linear equating method (Livingston, 2014) was applied to ensure comparability between forms, allowing them to be used interchangeably in subsequent analyses. The equating process resulted in adjusted maximum scores slightly exceeding the original scale; specifically, the pretest maximum increased to 9.91 and the posttest maximum to 10.82, compared to the original maximum of 9. However, this had no impact on the study, as the exact score range was not relevant to the research questions or analyses.

Self-explanation quality

Self-explanation quality is commonly assessed by the extent to which students connect their actions to underlying subject principles when responding to prompts (Beege & Ploetzner, 2025; Killingsworth et al., 2015; Nguyen et al., 2023). In this study, self-explanation quality was operationalized as students' use of targeted physics knowledge—specifically, the parallelogram method for vector addition—to explain their game solutions by constructing force diagrams. To support content validity, the rubric was developed in collaboration with a high school physics teacher, who also playtested the game to ensure alignment with the targeted physics concepts and problem-solving processes represented in the game.

The rubric evaluated students' performance across multiple components of force representation and vector construction. In Levels 9 and 10, students earned points for identifying gravitational and external forces and correctly constructing the resultant vectors. In Levels 11 to 13, additional points were awarded for sequentially combining two external forces to construct a second net force using the parallelogram method. One point was awarded for

有两个力，它们的合力为0，现在把其中一个向左的5 N的力改为向右（大小不变）。它们的合力大小变为： A. 0 B. 5N C. 10N D. >10N	There are two forces whose net force is 0. Now, one of the forces—a 5 N force initially pointing to the left—is changed to point to the right (with the same magnitude). The magnitude of the new net force becomes: A. 0 B. 5N C. 10N D. >10N
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Fig. 5 Example physics test item: original Chinese version (left) and translated English version (right)

each correctly completed component, and total scores were calculated by summing points across the five targeted levels (maximum score = 21).

Two trained raters independently evaluated the diagrams created by participants in the During and After conditions using this rubric. The raters—the first researcher and a graduate student with a physics background—underwent training and calibration prior to formal scoring to ensure consistent application of the rubric. Inter-rater reliability was excellent (intraclass correlation coefficient, $ICC = .991$, $p < .001$, 95% CI [.986, .994]). The final score for each participant was calculated as the average of the two raters' scores.

Observations and student interviews

Gameplay observations were conducted following a semi-structured protocol to document students' behaviors, such as their focus, off-task activities, and levels of engagement (e.g., interest or boredom). In addition, six students were selected from the two treatment conditions (three from each condition) for brief on-site interviews conducted during the gameplay session. These students were randomly selected to provide illustrative insights into learners' responses to the self-explanation prompts under the two delivery conditions. The small number of interviewees was determined by the time constraints of the 35-min in-class session and the on-site nature of data collection, and the interviews were intended to provide illustrative rather than representative insights. Interview questions focused on students' responses to and perceptions of the self-explanation prompts, including questions such as “Did you draw force diagrams?” and “Why did or didn't you draw them?” Observation field notes and interview responses were recorded in written form during data collection.

The qualitative data were analyzed using a focused thematic analysis approach (Creswell & Poth, 2017). Initial coding was guided by a pre-established coding schema centered on students' reactions to the game and their perceptions of the prompts. Subcategories were developed through iterative examination of the data within each coding category, and themes were identified and refined based on recurring patterns. The purpose of this analysis was to complement the quantitative findings by providing contextualized insights into students' gameplay behaviors and their engagement with the prompts.

Procedure

The study was conducted in the school computer lab over two 50-min sessions, with approximately 50 students participating per session (see Fig. 6). Given that self-explanation requires prior subject knowledge (Chi et al., 1989; Fukuda et al., 2024), all participants had received instruction on the targeted physics concepts as part of their regular curriculum prior to the study.

During each session, students first spent eight minutes completing a demographic survey and the physics knowledge pretest on the computer. They were then instructed to play the corresponding version of *Save Kitten* individually for 35 min. Students in the During and After conditions received a handout containing printed screenshots of the final five levels. Observations and student interviews were conducted concurrently with the 35-min gameplay session by the first researcher. Finally, students spent seven minutes completing the physics knowledge posttest.

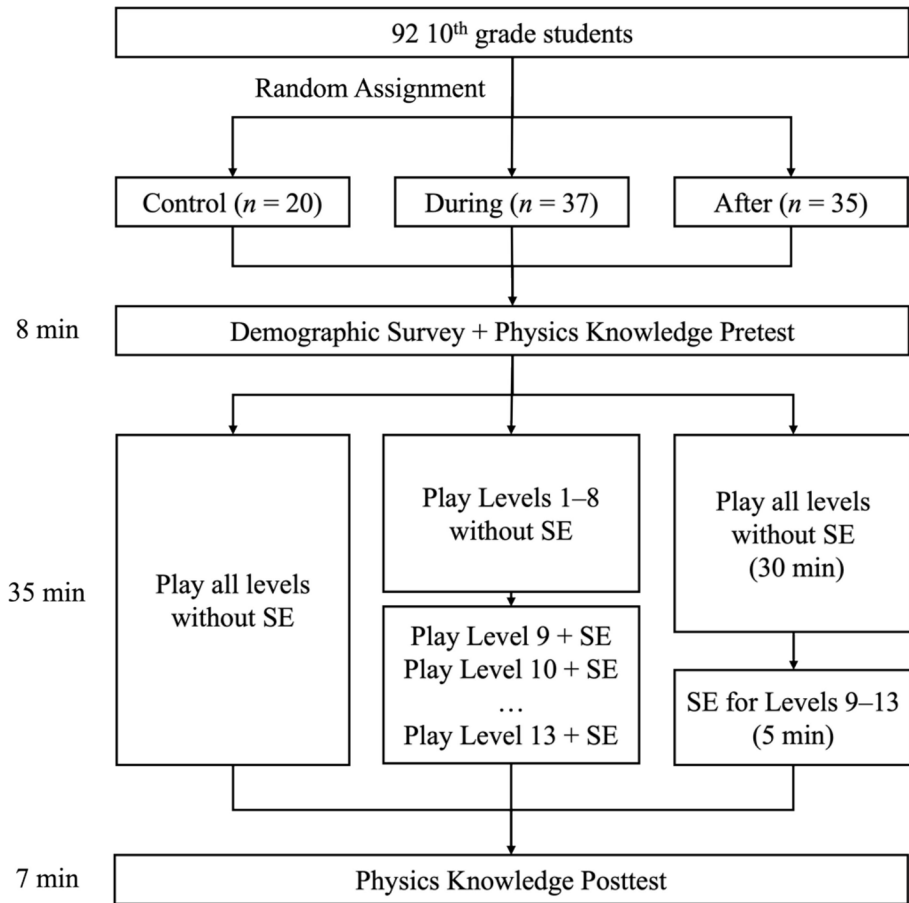


Fig. 6 Study procedure (*SE* self-explanation)

Results

Descriptive statistics

Descriptive statistics for physics knowledge pretest scores, posttest scores, and self-explanation quality were calculated for each condition. The During and After conditions were further combined into a single treatment condition, and its corresponding descriptive statistics were also computed (see Table 1).

RQ1—Effectiveness of prompting self-explanation on content learning

To address the question of whether prompting self-explanation is effective in improving students' content learning in educational games compared to no prompting, we compared the treatment group (During + After) to the control group on the posttest, controlling for the

Table 1 Descriptive statistics by conditions

	<i>n</i>	Physics knowl- edge pretest ^b		Physics knowl- edge posttest ^c		Self- explanation quality ^d
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>Mdn</i>
Control	20	6.64	1.46	5.05	2.24	n.a
During	37	6.53	1.68	7.70	1.95	3.00
After	35	6.89	1.99	6.18	3.13	0.00
Treatment ^a	72	6.70	1.83	6.96	2.68	2.50

^aTreatment is the combination of the during and after conditions

^bThe maximum score for the pretest was 9.91

^cThe maximum score for the posttest was 10.82

^dThe maximum score for self-explanation quality was 21.00

pretest. Consistent with H1, results from the one-way ANCOVA indicated that students in the treatment group scored significantly higher on the physics knowledge posttest ($n = 72$, $Adjusted\ M = 6.95$, $SE = 0.30$) than those in the control group ($n = 20$, $Adjusted\ M = 5.07$, $SE = 0.56$) after controlling for the pretest, $F(1, 89) = 8.85$, $p = .004$, $\eta^2 = 0.090$.

Furthermore, two paired-sample t -tests were conducted to compare students' posttest and pretest scores separately in the control and treatment groups. Results showed that students in the control condition exhibited a significant decrease in their posttest scores ($M = 5.05$, $SD = 2.24$) compared to their pretest scores ($M = 6.64$, $SD = 1.46$), $t(19) = 2.60$, $p = .018$, Cohen's $d = 0.84$. However, students in the treatment condition showed no significant difference between their pretest ($M = 6.70$, $SD = 1.83$) and posttest scores ($M = 6.96$, $SD = 2.68$), $t(71) = 0.81$, $p = .421$, Cohen's $d = 0.12$.

RQ2—Effects of prompting contexts on self-explanation quality

We compared students' self-explanation quality between the During and After conditions to address the question of which prompting context—during gameplay or after gameplay—leads to higher self-explanation quality. The histogram (see Fig. 7) reveals a high prevalence of zero self-explanation quality in both groups: 41% in the During condition and 51% in the After condition.

Roughly half of the students in both conditions did not provide any response to the prompts, resulting in a score of zero for self-explanation quality. A chi-squared test of independence was conducted and revealed no significant association between the proportion of zero cases and the conditions, $\chi^2(1) = 0.86$, $p = .35$. A Mann–Whitney U test was further employed and the results indicated no statistically significant difference in self-explanation quality between the During and After conditions, $U = 563.50$, $z = -1.00$, $p = .32$, $\eta^2 = 0.01$. Contrary to H2, students did not induce higher quality self-explanation in responding prompts delivered after the entire gameplay compared to during gameplay.

RQ3—Effects of prompting contexts on content learning

To answer the question of which prompting context—during gameplay or after gameplay—is more effective in improving content learning, an ANCOVA was conducted to compare students' posttest between the During and After conditions controlling the pretest.

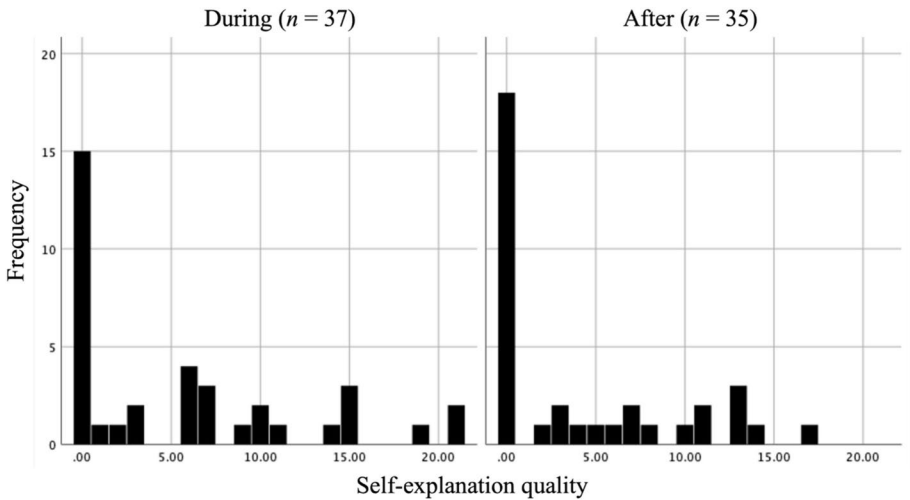


Fig. 7 Distribution of self-explanation quality in the during (left) and After (right) conditions

Contrary to H3, results showed that students in the During condition ($n=37$, *Adjusted* $M=7.80$, $SE=0.40$) scored significantly higher on the posttest than those in the After condition ($n=35$, *Adjusted* $M=6.08$, $SE=0.41$) controlling for their pretest scores, $F(1, 69)=9.15$, $p=.003$, $\eta^2=0.117$.

Additionally, paired-sample t-tests were performed within each condition to examine the changes in students' scores from the pretest to the posttest. The results indicated that students in the During condition showed a significant increase in their posttest scores ($M=7.70$, $SD=1.95$) compared to their pretest scores ($M=6.53$, $SD=1.68$), $t(36)=3.39$, $p=.002$, Cohen's $d=0.59$. In contrast, students in the After condition showed no significant difference between their pretest ($M=6.89$, $SD=1.99$) and posttest scores ($M=6.18$, $SD=3.13$), $t(34)=-1.45$, $p=.157$, Cohen's $d=0.27$.

Qualitative analysis results

Four patterns pertaining to students' reactions to and perspectives on the game and the self-explanation prompts emerged through thematic analysis.

Theme #1: Attention to peer performance during individual gameplay

Although students were instructed to play individually and the game included no competitive features such as a leaderboard, they consistently paid attention to their peers' in-game performance. This behavior emerged in two primary ways. First, students frequently engaged in progress comparisons by asking about or commenting on their peers' advancement through the game levels:

Student 1: "What level are you on?" (translated from Chinese by the researcher, same below).

Student 2: "Nine."

Student 1: "Wow, you're fast! I'm only on level eight."

Second, peer involvement was evident through direct interventions, such as a student pointing to a peer's screen and showing where to apply the external force. Students also openly discussed frustrations with challenging levels:

Student 3: "Ugh, the eleventh level is so hard. I don't think I'll ever get it."

Student 4: "Yeah, it's tough."

These interactions suggest that peer-driven attention to gameplay emerged organically, despite the absence of formal competitive structures. This emergent social dynamic appeared to prioritize rapid gameplay progress over deliberate reflection, potentially diminishing students' engagement with the self-explanation tasks.

Theme #2: Engagement gap between gameplay and academic tasks

Students demonstrated strong engagement during gameplay, as observed through their physical behaviors, such as leaning forward, maintaining eye contact with the screen, and minimizing off-task actions. Additionally, they exhibited determination and persistence, particularly in the later, more challenging levels, which required multiple attempts to complete. Upon successfully conquering these difficult levels, some students expressed excitement with remarks like, "I nailed it!" and "Yes, I won!"

In contrast, student engagement dropped significantly during the physics knowledge test. Many students expressed frustration, with comments such as, "Why do I still have to take a physics quiz?" and "Physics again?" Observations indicated that students often leaned back in their chairs, displaying signs of boredom or disengagement as they worked through the physics questions. This stark contrast highlights a notable disparity in motivation between gameplay and physics-related academic tasks.

Theme #3: Neglect of prompts in both treatment conditions

In both the During and After conditions, many students were observed to skip the self-explanation prompts and continue gameplay without engaging with them. In the During condition, students often directly clicked the "Continue" button when the prompt page appeared. When asked why, one student said, "I didn't see the prompts." Other students explained that drawing force diagrams took too much time and slowed down their gameplay: "It takes too long and messes with my game progress," and "I just want to keep solving levels faster." One student added that applying physics wasn't necessary for solving the puzzles: "I just keep adjusting my solution until it works."

Similarly, in the After condition, many students were observed quickly skimming the handout when the prompt page appeared, then returned to gameplay by clicking the "Menu" button (which was designed to help students refresh their gameplay memories for completing the self-explanation) or watching their peers play. One student, when asked why they didn't follow the prompts, explained:

Student 5: (Opening the screenshot page on the handout) "The ball and the balloon in the screenshots are both in their starting positions. To draw the force diagrams, I must move them to where I actually applied the arrows."

Researcher: "So?"

Student 5: "It's too complicated. I don't wanna go through that."

Theme #4: Implicit self-explanation during gameplay

Interestingly, some students in the During condition, while not engaging in explicit self-explanation by drawing force diagrams on the handout, reported conducting self-explanation implicitly in their minds. This mental approach allowed them to integrate self-explanation seamlessly into their gameplay experience without disrupting their progress.

One student, who had been observed skipping the prompts, explained:

Student 6: “I do the force diagrams in my head.” (pointing to the screen) “I just picture it. There’s a downward arrow for gravity pulling the ball and another arrow for the external force. Together, they make the ball go toward the balloon.”

Other students shared similar thoughts:

Student 7: “Drawing them on paper takes too much time. I just do it mentally.”

Student 8: “When I start a level, I first think about the forces, kind of like making a mental force diagram for the ball, and then I keep trying things until it works.”

Discussion

Gameplay alone can hinder learning; prompting self-explanation helps

This study provides empirical evidence supporting the use of voluntary, open-ended in-game prompts to induce self-explanation in game-based learning contexts. Students who received such prompts during or after playing *Save Kitten* showed greater learning gains than those who played alone. This finding echoes a large body of self-explanation literature (e.g., Chen et al., 2025; Shaheen et al., 2023; Wang & Xu, 2024) in highlighting that the self-explanation effect is applicable to game-based learning contexts. Meanwhile, this finding contrasts with prior studies that found mandatory, menu-based in-game prompts to be no more effective for content learning than gameplay without prompts (e.g., Adams & Clark, 2014; Clark et al., 2016; Fukuda et al., 2024; Killingsworth et al., 2015). It demonstrates the superiority of voluntary, open-ended prompt design in educational game environments: voluntary prompts act as gentle reminders without disrupting gameplay or hurting students’ sense of autonomy, while open-ended prompts are less prone to surface-level processing, such as guessing.

Compared to gameplay alone, when students are provided with such prompts requiring them to explain their game solutions using underlying subject concepts and principles, they are more likely to consciously reflect on their problem-solving and connect it to specific subject knowledge. This explicit connection between gameplay and academic content is critical for fostering meaningful learning in game-based environments (Chen & Chang, 2024; Shaheen et al., 2023; Yang et al., 2021). Specifically, self-explanation prompts can help students activate relevant prior knowledge, focus on subject-related key variables in game problems (e.g., the magnitude of gravitational force in *Save Kitten*), and apply subject knowledge to solve challenges rather than relying on trial and error. By doing so, students translate abstract subject knowledge into concrete application rules (e.g., how to apply the force composition principle to determine the net force on the small ball), leading to deeper conceptual understanding and transfer. Additionally, these prompts reinforce the educational purpose of the game. By encouraging students to reflect on their gameplay

through the lens of specific subject knowledge, the prompts can help them perceive the game as a legitimate learning tool rather than mere entertainment—a shift that may ultimately enhance academic outcomes.

This study also found that students who did not receive self-explanation prompts performed worse on the posttest compared to their pretest scores. Although *Save Kitten* provided a highly engaging gameplay experience based on the gameplay observation, the results indicate that engagement alone does not necessarily lead to meaningful content learning. This finding aligns with literature arguing that instructional support is necessary to facilitate effective experiential game-based learning (Alf et al., 2023; Bacalja, 2024; Chen & Chang, 2024; Pan et al., 2024; Shaheen et al., 2023). The decline in students' physics knowledge posttest scores when playing alone can be attributed to their overreliance on trial-and-error strategies, as the lack of an explicit connection between game problem solving and underlying content may lead to fragmented or flawed conceptual understanding (Barab et al., 2009; Chen & Chang, 2024). Another possible explanation is that students may harbor skepticism regarding the educational value of gameplay without additional instructional support (Squire, 2005), particularly in contexts like China, where video games are predominantly viewed as entertainment (Huang, 2024). This skepticism may have prevented students from recognizing the game as a legitimate subject learning tool, thereby limiting their cognitive investment in the physics knowledge posttest.

Prompting does not ensure meaningful engagement: implications from low response rates

It is well documented that self-explanation prompts delivered during gameplay are often disregarded, as learners' cognitive resources and motivation are primarily allocated to ongoing problem solving in the game (Adams & Clark, 2014; Baker et al., 2024; Nguyen et al., 2023). Consistent with these findings, nearly half of the students in the During condition in this study did not provide written responses to the prompts. The low written response rate may reflect both cognitive and motivational constraints. From a cognitive perspective, the prompts required students to reconstruct dynamic gameplay trajectories to generate force diagrams, potentially introducing substantial extraneous cognitive load. Such demands may have reduced students' willingness to interrupt gameplay to engage in written self-explanation. From a motivational perspective, although the prompts emphasized that self-explaining could support subsequent levels, the competitive classroom context appeared to encourage students to prioritize rapid level completion through trial-and-error rather than pausing to reflect on how underlying physics principles were applied. Importantly, the absence of written responses does not necessarily indicate a lack of cognitive engagement. Interview data suggested that some students reported processing the prompts mentally but chose not to externalize their responses in written or diagrammatic form. This pattern is consistent with Munby (1989), who argued that reflection-in-action is often intuitive and non-deliberate and may not be readily externalized.

We hypothesized that delaying prompt delivery until after gameplay—thereby positioning self-explanation as reflection-on-action rather than reflection-in-action (Schön, 1983)—would redirect students' attention away from gameplay and improve self-explanation quality. Contrary to this expectation, a similarly large proportion of students in the After condition did not respond to the prompts. One possible explanation is that the After condition imposed greater demands on learners due to the temporal separation between gameplay and prompting, requiring students to recall their problem-solving processes from

memory rather than respond in close proximity to the corresponding game actions. More importantly, separating self-explanation from gameplay did not necessarily shift students' engagement toward content learning. Qualitative data suggested that students showed resistance to engaging with physics-related content in the context of an information technology class. In the Chinese high school context, information technology is not included in the gaokao and is therefore often perceived as an opportunity for relaxation rather than academic learning. As a result, even after gameplay ended, many students appeared to remain mentally engaged with the gaming experience rather than with the intended reflective task. Some resumed gameplay using the "Menu" function, which was intended to support recall of prior actions, while others turned to peers to observe and discuss game performance. These findings suggest that the temporal separation alone was insufficient to shift students' goal orientation from gameplay performance to content learning, thereby limiting their engagement with self-explanation as a meaningful learning activity.

Greater learning gains in the during-gameplay prompting context

Contrary to our hypothesis, the results showed that self-explanation prompts embedded within ongoing gameplay led to greater content learning gains than prompts delivered after gameplay. Students in the During condition demonstrated significant learning gains, whereas those in the After condition showed no significant improvement.

The effectiveness of during-gameplay prompting for content learning can be explained by its alignment with the game-based experiential learning cycle (Kiili, 2005). In the During condition, self-explanation was embedded within ongoing gameplay, allowing students to iteratively move from concrete gameplay experience to reflection, abstraction of underlying physics principles, and subsequent testing of their understanding through continued game actions. In this way, during-gameplay prompts, whether responded to explicitly or implicitly, may facilitate content learning by supporting connections between game-based problem solving and underlying physics knowledge. These findings extend prior research linking higher-quality self-explanations to improved learning outcomes (e.g., Adams & Clark, 2014; Baker et al., 2024; Beege & Ploetzner, 2025; Chiou et al., 2025) by suggesting that both externally articulated and internally generated self-explanations may contribute to learning. However, this interpretation should be treated with caution, as the evidence for implicit self-explanation is based on limited interview data. Future research could employ think-aloud protocols to more directly examine the nature of these internal processes and their role in supporting learning.

The After condition was designed to deliver self-explanation prompts after the completion of gameplay in order to elicit reflection-on-action. We hypothesized that this prompting context would be more effective than during-gameplay prompting, as it would allow students to disengage from the immediate demands of gameplay and allocate greater cognitive and motivational resources to deliberate reflection. However, the results did not support this expectation. Importantly, this finding should not be interpreted as evidence against the effectiveness of reflection-on-action. Rather, the results suggest that after-gameplay prompts did not successfully shift students' goal orientation from performance to learning (Elliot & McGregor, 2001), thereby limiting meaningful engagement with the prompts as a learning activity. As discussed in "[Prompting does not ensure meaningful engagement: implications from low response rates](#)" section, many students remained focused on gameplay outcomes even after the session ended. Without a shift in goal orientation, the potential benefits of delayed self-explanation were not realized. Future research should examine

how after-gameplay self-explanation can be supported through more structured, instructor-led reflection contexts that position reflection as a required learning activity.

Limitations

This study has several limitations that should be acknowledged. First, due to scheduling constraints of the participating school, only 35 min of gameplay could be accommodated. While statistically significant differences were observed between conditions, the relatively short duration may have limited the extent to which the effects of self-explanation prompts could fully emerge, particularly with respect to more sustained or longer-term learning processes.

Second, the large class sizes (over 50 students per session) posed challenges for data collection. Although observations and student interviews provided useful insights, logistical constraints limited the depth of qualitative data and may not have captured the full range of students' experiences.

Third, the study was conducted in a single high school in southern China with tenth-grade students, focusing on a physics topic (force composition). Therefore, the findings may not fully generalize to other grade levels, schools, subject areas, or educational contexts.

Finally, the study took place in an authentic classroom environment where peer interaction was present. Such contextual factors may have influenced students' engagement with the prompts. Consequently, the findings may not fully generalize to settings in which students engage in gameplay individually or under more controlled conditions.

Conclusion and implications

Educational games hold significant potential to support experiential learning through game-based problem solving. However, this study shows that such experiences do not automatically translate into meaningful content learning without opportunities for reflection that connect gameplay actions to underlying content knowledge. This study contributes to the literature on reflective prompting in game-based learning by showing that prompting can support learning, but that different forms of reflection—reflection-in-action and reflection-on-action—operate through distinct mechanisms and therefore require different forms of design to ensure meaningful engagement with prompts. These findings have important implications for the design of self-explanation prompts in both during-gameplay and after-gameplay prompting contexts.

For during-gameplay prompting, the findings suggest that its effectiveness depends on how well prompts are integrated into the gameplay process. Rather than being presented as isolated interruptions, prompts should be placed at moments when learners have just completed a meaningful problem-solving action and can use reflection to inform subsequent gameplay. For example, prompts can be linked to game feedback, strategy revision, or the next attempt at a similar problem, helping students see self-explanation as useful for both understanding the content and progressing in the game. Open-ended and voluntary prompts may further reduce disruption by allowing learners to respond in ways that fit the gameplay context, whether verbally, mentally, or in writing. In this way, during-gameplay prompts can function as light scaffolding that directs learners' attention to underlying domain knowledge while preserving the flow of gameplay.

For after-gameplay prompting, the findings indicate that simply presenting on-screen prompts after gameplay is insufficient to elicit meaningful engagement. Because students may still interpret the activity through a gameplay-performance orientation, post-game self-explanation needs to be embedded in a more structured reflection context. For example, teachers can guide students to revisit key game events, compare solution strategies, examine examples of high-quality explanations, or discuss how specific gameplay actions reflect underlying disciplinary principles. Together, these supports can help position self-explanation as a meaningful learning task and shift learners' attention from game completion to content understanding.

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Declarations

Competing interests The authors declare no competing interests.

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