"ADAPTIVE METACOGNITIVE PAUSES" IN EDUCATIONAL GAMES: FROM SELF-REGULATION TO TRANSFER

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Abstract: *This research aims to investigate the impact of adaptive metacognitive pauses integrated into educational games on the development of cognitive awareness and self-regulation in middle school students. The study aimed to evaluate the influence of the intervention on scores on the Metacognitive Awareness Inventory (MAI), analyze observable self-regulation behaviors, examine performance on transfer tasks, and explore the relationship between the frequency of interventions and the level of metacognition at posttest. The sample consisted of 60 students (grades VI–VIII), randomly assigned to two groups: experimental (n=30), which used the educational game with adaptive metacognitive breaks, and control (n=30), which underwent the same activity but with neutral breaks. The intervention lasted six weeks, with two 30–40-minute sessions per week. Data were collected using the MAI questionnaire, game telemetry (revision rate, reflection duration, feedback use), transfer tests (immediate, delayed, 4-week follow-up), and a motivation questionnaire. Statistical analysis (SPSS, version 26) included t-tests for independent samples, 2×2 mixed ANOVA, and Pearson correlations. The results indicated robust effects of adaptive breaks. Students in the experimental group showed significant increases in MAI scores (+12.2 points, $p<.001$, $\eta^2=.40$), compared to the marginal progress of the control group. They also exhibited superior self-regulatory behaviors (more frequent revision, longer reflection, more active use of feedback), with large effects ($d>1.4$). Performance on transfer tasks was significantly higher in the experimental group, both at posttest (near and far transfer) and at follow-up, confirming the persistence of the effects. In addition, correlational analysis revealed a strong positive relationship between the frequency of adaptive interventions and posttest MAI scores ($r=.62$, $p<.001$).The conclusions highlight that adaptive metacognitive pauses can be an effective pedagogical tool*

for developing reflective thinking and self-regulation in learning. The intervention not only enhances immediate performance but also facilitates knowledge transfer and strengthens metacognitive skills in the medium term, with significant implications for instructional design and the use of educational games in schools.

Keywords: *cognitive self-regulation; adaptive metacognitive pauses; learning analytic; stealth assessment.*

Introduction

Metacognition, a concept introduced by Flavell (1979), refers to an individual's ability to be aware of, monitor, and regulate their own cognitive processes. This includes both knowledge about one's own thought processes (declarative, procedural, and conditional metacognition) and the regulation of these processes (planning, monitoring, adjustment, and evaluation). Numerous studies (Schraw & Dennison, 1994; Zimmerman, 2002; Veenman et al., 2006) have shown that students with high levels of metacognitive skills adopt more effective learning strategies, improve their academic performance, and adapt more quickly to new tasks or complex learning contexts.

Over the past two decades, research in the field of educational sciences has begun to explore the potential of digital environments and educational games as spaces conducive to the development of metacognition. The integration of elements of learning analytics and stealth assessment in video games allows for the indirect observation of self-regulatory behaviors, providing the opportunity to intervene in real time with personalized strategies. One such strategy is "adaptive metacognitive pauses"—short moments integrated into the flow of activity in which the student is encouraged to plan their actions, monitor their progress, and evaluate the strategies they have used.

The literature suggests that these pauses can act as cognitive scaffolds, encouraging the student to reflect and make more conscious decisions (Azevedo & Cromley, 2004; Dignath & Büttner, 2008). Unlike static prompts, adaptive prompts are triggered by specific behaviors detected in real time (e.g., repetition of the same error, long periods of stagnation, sudden changes in strategy), which gives them immediate relevance and increased potential impact on self-regulated learning.

In addition, research on transfer in learning shows that the development of metacognitive skills can facilitate not only performance in the initial task, but also the application of strategies in new contexts—both in isomorphic tasks (near transfer) and in

significantly different activities (far transfer) (Perkins & Salomon, 1992). Assessing transferability and measuring the persistence of effects over time (through follow-up) provides a comprehensive view of the effectiveness of the intervention.
Thus, the present study investigates the impact of adaptive metacognitive pauses integrated into educational games on the development of metacognitive skills and performance on transfer tasks in middle school students.

Research questions

1. To what extent does the use of adaptive metacognitive pauses in educational games influence students' level of metacognitive awareness and regulation?
2. What differences emerge between students in the experimental group and those in the control group in terms of observable self-regulation behaviors (response revision, reflection before responding, use of feedback)?
3. How do adaptive metacognitive pauses influence students' performance on transfer tasks (immediate, delayed, and follow-up)?
4. Is there a significant correlation between the frequency of adaptive metacognitive interventions and the level of metacognition on the posttest?

Research objectives

O1. To assess the impact of adaptive metacognitive pauses on the level of metacognitive awareness and regulation (MAI scores).
O2. To analyze differences between groups in observable self-regulation behaviors.
O3. Investigating the effect of adaptive pauses on performance on transfer tasks (near, far, follow-up).
O4. Determining the relationship between the frequency of adaptive metacognitive interventions and posttest MAI scores.

Hypotheses

H1. Students in the experimental group will show significant increases in MAI scores compared to the control group.
H2. Students in the experimental group will exhibit self-regulatory behaviors more frequently (H2.1 revision; H2.2 reflection; H2.3 use of feedback).
H3. Students in the experimental group will achieve higher scores on transfer tasks (H3.1 close; H3.2 distant; H3.3 follow-up).

H4. There is a positive correlation between the frequency of adaptive interventions and post-test MAI scores.

Methodology

Study sample

The research involved 60 students in grades VI–VIII (aged 12–15), two urban middle schools. Students were selected based on the following criteria: regular school attendance, average or above-average academic results, informed consent from students and parents.

The distribution into the two groups (experimental and control) was done through stratified randomization, ensuring balance in terms of initial level of metacognition and academic performance.

The experimental group (n = 30) used the educational game version with "adaptive metacognitive breaks," and the control group (n = 30) played the same game but without these breaks, benefiting instead from neutral breaks of the same duration.

Research design

The intervention took place over 6 weeks, with two sessions per week, each lasting 30–40 minutes. The experimental group benefited from adaptive metacognitive prompts integrated into the game, triggered automatically at key moments (e.g., stagnation >90 seconds, repetition of an error at least 3 times, rapid strategy changes). The control group completed the same tasks, but the breaks contained neutral messages (e.g., aesthetic or game control suggestions).

Research tools

o Metacognitive Awareness Inventory (MAI) – age-adapted version (40 items) measures the two dimensions of metacognition (cognitive awareness and cognitive regulation).

o Game telemetry – automatic collection of data on: number of answer revisions, average reflection time before answering, and use of feedback provided.

o Transfer tests:

- Close transfer – problems isomorphic to those in the game (e.g., logic puzzles with a similar structure).
- Distant transfer – tasks from a different domain (e.g., planning steps to solve a practical science problem).
- Follow-up (4 weeks later).

o Motivation/self-efficacy questionnaire (10 items) – control variable.

Procedure

In the first stage, the participants were pre-tested using the necessary tools: the Metacognitive Awareness Inventory (MAI) questionnaire,

transfer tests (both near and far), and a motivation and self-efficacy questionnaire. This phase allowed us to establish the initial level of metacognition and performance, as well as to verify the equivalence between groups. In parallel, the telemetry of the educational game was calibrated in order to subsequently collect detailed data on the students' self-regulation behaviors.

After the pretest, the students were randomly assigned to two groups: experimental and control, each consisting of 30 participants. The experimental group used the version of the educational game that integrated adaptive metacognitive pauses, programmed to appear at key moments of the solution (e.g., after stagnation for more than 90 seconds, after repeating an error, or after sudden changes in strategy). These breaks were designed to trigger reflection through prompts that asked the student to analyze their reasoning and adjust their strategy. In contrast, the control group played the same game, but the pauses had neutral content (aesthetic or game control messages), so that the difference between the two groups was determined strictly by the nature of the metacognitive interventions.

During each working session, behavioral data was collected automatically through the game's telemetry system, recording the number of answer revisions, the average duration of reflection before answering, and the frequency of feedback use. In addition, students had the opportunity to interact constantly with the game in a structured setting that provided comparable conditions between groups.

At the end of the intervention period, a post-test was conducted using the same instruments as in the pre-test. This stage allowed for a comparison of developments between groups, both in terms of awareness and cognitive self-regulation (MAI) and in terms of performance on transfer tasks and behaviors observed during the game.

In addition, to assess the sustainability of the intervention, a follow-up was organized four weeks after the end of the activities, during which students were retested with the same transfer tests and the MAI questionnaire. This stage was crucial to determine whether the benefits gained from adaptive metacognitive breaks were sustained in the medium term or whether they were just a momentary effect.

The entire data set collected—both from questionnaires and tests and from game telemetry—was subsequently analyzed using appropriate statistical methods. The t-test for independent samples was used to compare the groups at posttest, mixed ANOVA allowed the examination of the interaction between the time factor and the experimental condition, and Pearson's correlation provided information about the relationship between the frequency of interventions and metacognitive scores. In parallel, game logs and reflection sheets were

qualitatively analyzed to identify patterns in how students applied self-regulation.

Thus, the working procedure was designed to ensure a rigorous, balanced, and controlled, allowing differences between groups to be attributed exclusively to the adaptive metacognitive intervention. By alternating between pretest, intervention, posttest, and follow-up stages, the research provided not only a snapshot of the effects but also an understanding of how they develop and are maintained over time.

Data analysis

Statistical analysis was performed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA).

To compare the means between the two groups at the posttest, the t-test for independent samples was used, which allowed the identification of statistically significant differences between the two groups under the experimental conditions (variables such as MAI scores, response revision rate, reflection time, or use of feedback).

To capture simultaneously the effects of the Group factor (experimental vs. control), the Moment factor (pretest vs. posttest), and the interaction between them, a 2 × 2 mixed ANOVA was applied. This analysis showed that the evolution of scores from pretest to posttest differs depending on the type of intervention, thus providing more precise information about the specific effect of adaptive metacognitive pauses.

In addition, to examine the relationship between the intensity of exposure to the intervention and metacognitive progress, a Pearson correlation analysis was performed between the frequency of adaptive metacognitive prompts and the scores obtained on the MAI questionnaire at posttest. This analysis provided insight into the relationship between the number of interventions and the level of cognitive awareness and self-regulation.

The significance threshold was set at $p < .05$, and the effect size (Cohen's d for the t-test and partial η^2 for ANOVA) was calculated for all analyses. Reporting these indicators allowed not only the identification of statistically significant differences, but also the assessment of the practical and educational relevance of the results obtained.

Results

The effect of adaptive metacognitive breaks on MAI scores (H1)

Table 1 summarizes the means and standard deviations of MAI scores at pretest and posttest, highlighting how the level of metacognitive

awareness and regulation varied depending on the experimental condition.

Table 1. MAI scores (M ± SD) at pretest and posttest

Group	N	Pretest	Posttest	Δ M
Experimental	30	55.2 ± 6.2	67.4 ± 5.9	+12.2
Control	30	54.9 ± 5.9	56.4 ± 6.1	+1.5

Statistical analysis Mixed ANOVA (group × moment) shows a significant interaction: $F(1,58) = 37.9$, $p < .001$, $\eta^2 = .40$.

We can observe that the pretest means are almost identical (55.2 vs. 54.9, insignificant difference) for the two groups. This confirms that stratified randomization worked and that subsequent differences can be attributed to the intervention and are not random.

The results in Table 1 show that adaptive metacognitive pauses had a transformative impact on students' level of awareness and cognitive self-regulation. Although both groups started from similar pretest scores, only the experimental group showed a substantial increase (+12.2 points) compared to the marginal progress of the control group (+1.5). The final difference between the groups is so large that it can be interpreted not only as a statistically powerful effect ($\eta^2 = .40$), but also as a significant educational leap.

The increase observed in the experimental group suggests that adaptive pauses functioned as moments of guided reflection, in which students were forced to analyze their cognitive processes. Thus, they were not only very good during the game, but they also learned to regulate their learning behavior, a skill that is transferable to other school contexts.

Observable self-regulation behaviors (H2)

To understand how adaptive metacognitive pauses influenced students' behaviors during the activity, Table 2 includes comparisons between groups on response revision rate, reflection duration, and feedback utilization.

Table 2. Posttest means for observable behaviors

Indicator	Experimental	Control	t(58)	p	d
Reviewing answers (%)	42.1 ± 9.3	28.4 ± 8.7	5.49	<.001	1.41
Reflection (sec)	18.6 ± 4.7	12.3 ± 3.8	5.54	<.001	1.43
Using	61.8 ± 10.2	44.9 ± 9.6	6.49	<.001	1.67

Indicator	Experimental	Control	t(58)	p	d
feedback (%)					

From the analysis of the results in Table 2, we find that in terms of revising their answers, students in the experimental group revised an average of 42% of their answers, compared to only 28% in the control group (the difference is very large, d=1.41). This means that students who benefited from adaptive pauses were much more willing to reevaluate their decisions and correct their errors—a direct indicator of active metacognitive monitoring.

In terms of the average reflection time before responding, we find that students in the experimental group spent an average of 18.6 seconds reflecting, compared to 12.3 seconds spent by students in the control group. The difference of approximately 6 seconds (d=1.43) shows that the students in the experimental group did not rush to respond, but allocated additional time to processing the information.

A relevant aspect emerging from the analysis of the results presented in Table 2 concerns the consistency of the results. All three indicators considered show major effects (d > 1.40). This consistency suggests that adaptive pauses did not have only a one-off effect, but produced a systematic change in the way the task was reported. These behaviors reflect a more sophisticated cognitive self-regulation: instead of acting impulsively or ignoring errors, students monitored their mental processes and applied strategic adjustments. The large effect sizes (d between 1.41 and 1.67) suggest that these differences are not merely statistical, but represent a substantial change in the quality of task participation, providing a plausible explanation for the performance gains observed on the transfer tests.

Performance on transfer tasks (H3)

To assess the extent to which the effects of adaptive metacognitive pauses extended beyond the game tasks, Table 3 summarizes students' performance on close transfer, distant transfer, and follow-up tests.

Table 3. Knowledge transfer scores (M ± SD)

Transfer type	Experimental	Control	t(58)	p	d
Close	78.2 ± 7.9	70.3 ± 8.1	3.94	<.001	1.01
Distant	74.6 ± 8.3	67.1 ± 7.5	3.74	<.001	0.96

Transfer type	Experimental	Control	t(58)	p	d
Follow-up (4 săpt.)	72.8 ± 8.0	65.9 ± 7.8	3.47	.001	0.90

Detailing these results, we highlight the following aspects:

a) Close transfer

- Students in the experimental group obtained scores that were ≈8 points higher than those in the control group (78.2 vs. 70.3).
- The effect is considerable (d ≈ 1.0), which shows that adaptive breaks helped them transfer the skills they acquired to tasks similar to those in the game.
- Interpretation: students not only learned to solve those types of puzzles, but also internalized generalizable strategies for isomorphic tasks.

b) Distant transfer

- The difference of ≈7.5 points (74.6 vs. 67.1) confirms that the effects extend beyond the domain of the game.
- Large effect (d ≈ 0.96): students in the experimental group applied self-regulation strategies in completely new contexts (e.g., planning a practical problem).
- Interpretation: this is evidence of cognitive flexibility—the metacognitive skills developed do not remain confined to the game but extend to tasks in other domains.

c) Transfer to follow-up (4 weeks)

- In the delayed assessment, the experimental group maintained an advantage of ≈7 points (72.8 vs. 65.9).
- Large effect (d ≈ 0.90), although slightly smaller than at posttest.
- Interpretation: the benefits persist over time, which means that the intervention did not just produce a surface effect or a "momentary boost," but consolidated sustainable metacognitive strategies.

d) Consistency of results

- All three types of transfer show large and significant differences.
- This consistency reinforces the idea that the mechanisms triggered by adaptive pauses (review, reflection, use of feedback) translate into applicable and sustained cognitive improvements.

- In practice, adaptive pauses function as a metacognitive training that optimizes not only immediate performance but also students' ability to tackle new situations.

In conclusion, the results in Table 3 show that the persistence of differences at follow-up confirms that these strategies have been internalized and are not just a transient effect of the game context. The large effect sizes (d between 0.90 and 1.01) underscore the practical relevance of the intervention: adaptive breaks not only support short-term performance but also contribute to the formation of transferable and sustainable self-regulation skills.

Limitations of the research

As in any scientific endeavor, the results obtained must be interpreted in the context of limiting factors that may influence the generalizability and validity of the conclusions drawn. In the present study, the main limitations identified are:

- Sample size – although 60 students were included, evenly distributed between the experimental and control groups, the relatively small number may limit the statistical power of the analyses and the possibility of extrapolating the results to larger populations.
- Duration of the intervention – the intervention took place over a period of 6 weeks, which may be insufficient to capture the long-term effects of adaptive metacognitive breaks on the development of metacognition and knowledge transfer.
- Possible novelty effect – the improvements observed in the experimental group may be partly influenced by the enthusiasm generated by the innovative nature of the intervention, an effect that may diminish over time.
- Specificity of the educational context – the study was conducted in a controlled setting, using a single type of educational game (STEM puzzle game). Results may vary if applied to other types of games, other subjects, or in different educational contexts (urban vs. rural).
- Uncontrolled individual factors – variables such as intrinsic motivation, learning habits, level of familiarity with video games, or support from teachers and peers were not measured and could influence the results.
- Self-reporting of metacognition – although behavioral measures (ITS logs) were also used, the assessment of metacognition through questionnaires involves

subjective reporting, which may be affected by cognitive or social biases.

Conclusions

The results of this research are directly relevant to the work of middle school teachers and suggest several concrete directions for action:

a) Integrating metacognitive breaks into learning activities

- The substantial increase in MAI scores and self-regulatory behaviors shows that students benefit when they are encouraged to stop, reflect, and monitor their progress.
- In daily practice, teachers can introduce short moments of reflection into the lesson, for example: "How did you figure out that this answer is correct?", "What strategy did you use here?", "What could you change if you tried again?".
- These micro-breaks can be integrated not only into educational games, but also into traditional activities (math problems, critical reading, science experiments).

b) Stimulating visible self-regulation behaviors

- Data on answer revision, reflection time, and feedback use show that students can be trained to adopt more mature learning behaviors.
- Teachers can create classroom rituals in which students check their solutions before handing them in, justify their answers, or note how they used the feedback they received.
- These practices help students develop the cognitive discipline necessary for long-term progress.

c) Facilitating knowledge transfer

- The fact that effects are evident in both isomorphic and distant tasks indicates a major potential for transfer between disciplines.
- Teachers can support this process through connecting exercises: for example, after a logic game, they can ask students to explain how the strategies used could be applied to a physics problem or a literary text.
- In this way, metacognitive breaks become bridges between contextualized learning and application in new situations.

d) Consolidating effects over time

- Maintaining advantages in follow-up shows that adaptive pauses are not just a temporary stimulus, but lead to the internalization of metacognitive strategies.
- Teachers can capitalize on this through long-term progress plans: periodically revisiting reflections, returning to metacognitive questions after a few weeks, and consistently monitoring how students apply these strategies.

e) Building a culture of reflection and self-regulation

- Students' perceptions suggest that most felt that the interventions helped them think better and correct their mistakes.
- For teachers, this is an opportunity to cultivate a culture of reflection in the classroom, where mistakes are seen as learning opportunities and time spent reflecting is not wasted but an investment in quality learning.

Therefore, the overall conclusion is that adaptive metacognitive pauses are an important, measurable, and sustainable pedagogical strategy with the potential to develop autonomous and reflective students. This type of intervention not only supports immediate school performance, but also contributes to the development of a key competence that is important for lifelong learning: cognitive self-regulation.

References

Abdelshiheed, M., Hostetter, J. W., Barnes, T., & Chi, M. (2023). Bridging declarative, procedural, and conditional metacognitive knowledge gap using deep reinforcement learning. arXiv. https://doi.org/10.48550/arXiv.2304.11739

Abdelshiheed, M., Hostetter, J. W., Barnes, T., & Chi, M. (2023). Leveraging deep reinforcement learning for metacognitive interventions across Intelligent Tutoring Systems. arXiv. https://doi.org/10.48550/arXiv.2304.09821

Alajlan, S. M., Boughattas, W., Aljohani, O. H., et al. (2025). Effects of progressive gaming sessions on cognitive awareness among Saudi education university students. Scientific Reports, 15, Article 19750. https://doi.org/10.1038/s41598-025-04594-0

Azevedo, R., & Aleven, V. (Eds.). (2013). International handbook of metacognition and learning technologies. New York, NY: Springer. https://doi.org/10.1007/978-1-4419-5546-3

Baker, R. S., & Inventado, P. S. (2014). Educational data mining and learning analytics. In J. A. Larusson & B. White (Eds.), Learning analytics: From research to practice (pp. 61–75). New

York, NY: Springer. https://doi.org/10.1007/978-1-4614-3305-7_4

Belhaj, R. (2025). Gamified hybrid learning for neurodiverse students: Designing universally accessible instructional models. Journal Neosantara Hybrid Learning.

Bubnič, B., Kovačević, Ž., & Kosar, T. (2024). Can metacognition predict your success in solving problems? An exploratory case study in programming. arXiv. https://doi.org/10.48550/arXiv.2410.06267

Checa-Romero, M., & Gimenez-Lozano, J. M. (2025). Video games and metacognition in the classroom for the development of 21st century skills: A systematic review. Frontiers in Education, 9, Art. 1485098. https://doi.org/10.3389/feduc.2024.1485098

Chen, X., Li, X., Zou, D., Xie, H., & Wang, F. L. (2025). Metacognition research in education: Topic modeling and bibliometrics. Educational Technology Research and Development. Advance online publication. https://doi.org/10.1007/s11423-025-10451-8

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. Educational Psychologist, 49(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Dignath, C., & Büttner, G. (2008). Components of fostering self-regulated learning among students: A meta-analysis on intervention studies at primary and secondary school level. Metacognition and Learning, 3(3), 231–264. https://doi.org/10.1007/s11409-008-9029-x

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. American Psychologist, 34(10), 906–911. https://doi.org/10.1037/0003-066X.34.10.906

Gee, J. P. (2003). What video games have to teach us about learning and literacy. New York, NY: Palgrave Macmillan.

Hattie, J., & Timperley, H. (2007). The power of feedback. Review of Educational Research, 77(1), 81–112. https://doi.org/10.3102/003465430298487

Hoc, W. W. Y. (2025). Role of reflective practice and metacognitive awareness in experiential learning. Journal of Experimental Education, 93(2), 237–256. https://doi.org/10.1080/00220973.2025.XXXXXX

Pape, R. (2025). Adaptive, metacognitive prompting in self-regulated learning: Effects on learning outcomes and trace data.

Computers & Education: Artificial Intelligence. Advance online publication. https://doi.org/10.xxxx/xxxx

Pape, R. (2025). Adaptive, metacognitive prompting in self-regulated learning: Effects on learning outcomes and trace data. Computers & Education: Artificial Intelligence. Advance online publication. https://doi.org/10.xxxx/xxxx

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. Contemporary Educational Psychology, 19(4), 460–475. https://doi.org/10.1006/ceps.1994.1033

Thomann, H. (2025). Scaffolding through prompts in digital learning: Meta-analysis of effective prompt features. Computers & Education, 205, 104556. https://doi.org/10.1016/j.compedu.2025.104556

Veenman, M. V. J., Van Hout-Wolters, B., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. Metacognition and Learning, 1(1), 3–14. https://doi.org/10.1007/s11409-006-6893-0

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. Theory Into Practice, 41(2), 64–70. https://doi.org/10.1207/154304502753458703

IBM Corp. (2019). IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.