

Augmented Reality and Cognitive Conflict: Evidence from a Study on Conceptual Inhibition in High School Students

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Abstract: The study investigates the influence of Augmented Reality (AR) on cognitive conflict between perceptual and conceptual representations in a sample of 72 upper secondary school students. The experimental group used the Merge Cube to explore the brain's anatomical structures in 3D, while the control group attended a traditional lesson with printed materials. Both groups completed a multiple-choice test designed to elicit semantic-perceptual conflict, presenting intuitively plausible but conceptually incorrect alternatives alongside the correct answer. Selecting the right option required inhibiting the automatic tendency to favor the most salient choice and accessing a more abstract conceptual representation consistent with the scientific rule. The results, in line with conflict monitoring models (Botvinick et al., 2001; Egner & Hirsch, 2005), suggest that the use of AR can enhance inhibitory control and the resolution of cognitive conflict, supporting the role of prefrontal areas in the selection of competing representations (Krawczyk, 2012).

Keywords: Augmented reality; Cognitive conflict; Conceptual learning; Inhibitory control; Secondary education; Neuroanatomy learning



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1. Introduction

In educational settings, cognitive conflict is often exacerbated by the nature of instructional materials. Static, two-dimensional representations may reinforce visually salient but conceptually misleading cues, particularly in domains requiring the integration of complex spatial relationships and abstract structures. In such cases, learning difficulties do not stem solely from a lack of information, but from the challenge of

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coordinating perceptual inputs with conceptual rules. Addressing this challenge requires instructional environments capable of mediating the relationship between perception and conceptual understanding.

Within this framework, augmented reality (AR) has emerged as a promising educational technology. AR systems allow digital content to be superimposed onto the physical environment, enabling learners to interact with three-dimensional representations in real time. Previous research has documented the educational potential of AR across different levels of instruction, highlighting benefits in terms of engagement, motivation, and learning outcomes (Akçayır & Akçayır, 2017; Garzón et al., 2019; López-Belmonte et al., 2023). Systematic reviews and meta-analyses further indicate that AR can support learning when appropriately integrated into instructional design, while also pointing to the importance of avoiding cognitive overload and ensuring pedagogical coherence (Akçayır & Akçayır, 2017; Garzón et al., 2019).

Beyond general learning outcomes, an emerging body of research suggests that AR may influence core cognitive processes relevant to the management of cognitive conflict. Educational studies explicitly grounded in conflict-based learning frameworks have shown that AR environments can make discrepancies between students' preconceptions and scientific explanations more salient, thereby supporting conceptual restructuring and improved scientific literacy (Mufit & Dhanil, 2024; Dhanil & Mufit, 2025; Mufit et al., 2025). Converging evidence from experimental research further indicates that AR presentation modalities can modulate perceptual interference and attentional demands, suggesting an interaction between augmented visual information and mechanisms of conflict detection and resolution (Dempo et al., 2022).

Taken together, these findings position AR as a potential didactic mediator in learning situations characterised by competition between perceptual and conceptual representations. Rather than functioning solely as a motivational or illustrative tool, AR may shape the conditions under which cognitive conflict is experienced and managed. However, empirical evidence directly addressing the role of AR in the resolution of semantic–perceptual conflict remains limited, particularly in relation to complex anatomical content in secondary education.

Building on this gap, the present study investigates whether exposure to augmented reality supports more effective management of cognitive conflict compared to traditional static materials. Specifically, the study examines students' performance in a learning task designed to elicit semantic–perceptual conflict, in which correct responding requires inhibiting perceptually salient but conceptually incorrect alternatives and selecting scientifically accurate representations.

2. Augmented Reality as a Didactic Mediator

Within contemporary educational contexts, augmented reality (AR) has progressively emerged as a didactic mediator capable of reshaping teaching and learning processes through the integration of digital content into physical environments. Among the various innovations enabled by Information and Communication Technologies (ICT), AR stands out for its potential to transform traditional instructional models into immersive and interactive learning experiences (Saidin et al., 2015; Kesim & Ozarslan, 2012). By superimposing digital information onto real-world settings in real

time, AR enables learners to interact dynamically with content, fostering deeper engagement and more meaningful knowledge construction (Elmqaddem, 2017; Chen et al., 2017).

From a pedagogical perspective, AR functions as a mediator that supports the connection between abstract concepts and concrete experience, facilitating understanding through multisensory and exploratory interaction (Martin et al., 2018). This mediating role is particularly relevant across all levels of education, from early childhood, where AR stimulates curiosity and cognitive play (López Belmonte et al., 2020), to secondary and higher education, where it supports the comprehension of complex and abstract content through three-dimensional visualizations and interactive simulations (Lembo et al., 2024). Empirical research highlights several educational benefits associated with the use of AR, including increased student engagement, greater learner autonomy, and enhanced responsibility in the learning process (Akçayır & Akçayır, 2017). Additionally, AR has been shown to promote the development of digital competencies (Garzón et al., 2019), strengthen intrinsic motivation, and support attention regulation and concentration during learning activities (Koumpouros, 2024). The possibility of exploring content through discovery-based and experiential approaches aligns with constructivist and collaborative learning models, encouraging active participation and deeper cognitive processing. Furthermore, augmented reality offers significant opportunities for inclusive education by allowing the personalization of sensory inputs, visual, auditory, and tactile, according to learners' individual needs. This adaptability makes AR a valuable resource for addressing special educational needs, fostering equity, accessibility, and positive learning environments (Espinosa, 2015). As a result, AR is increasingly recognized within the international educational landscape as a powerful didactic mediator and one of the most widely explored technologies in recent educational research (Akçayır & Akçayır, 2017). Its integration into innovative pedagogical models, such as the flipped classroom, further enhances its mediating function, positioning AR as a catalyst for experiential learning, autonomous knowledge construction, and deep cognitive engagement.

2.1 Augmented Reality and Cognitive Conflict: The Role of the Merge Cube

Within the present study, augmented reality was employed as a cognitive mediation tool to investigate the processes involved in managing conflict between perceptual and conceptual representations. In particular, the use of the Merge Cube enabled the introduction of a three-dimensional and interactive mode of exploration of brain anatomical structures, fostering a deeper integration between visual information and conceptual knowledge (Taufiq et al., 2021; Ntuli, 2019). Unlike traditional two-dimensional materials, augmented reality visualization allows students to directly manipulate models, observe them from multiple perspectives, and construct coherent spatial relationships among their components, thereby reducing the risk of interpretations based solely on perceptually salient but conceptually misleading cues (Cowin, 2020; Voštinár et al., 2023).

In this sense, the Merge Cube should not be regarded merely as a technological support, but rather as a didactic mediator capable of eliciting processes of cognitive restructuring and executive control. Interaction with three-dimensional models can indeed make the conflict between perceptual intuitions and formalized scientific knowledge more explicit, facilitating the activation of conflict monitoring mecha-

nisms and the inhibition of automatic responses (Botvinick et al., 2001; Egner & Hirsch, 2005).

Selecting the correct response in the presence of perceptually plausible yet conceptually incorrect alternatives requires the engagement of executive functions, particularly inhibitory control processes and the selection among competing representations, which are associated with the activity of prefrontal brain areas (Krawczyk, 2012). From this perspective, augmented reality experiences may support a more effective integration of perceptual and conceptual information, promoting a more stable and abstract scientific understanding. The use of the Merge Cube thus emerges as a didactic resource capable of transforming cognitive conflict from an obstacle into a lever for learning, facilitating the transition from intuitive knowledge to a conceptually grounded representation.

3. Research Project

3.1 *Research hypothesis*

The present study hypothesizes that students who use augmented reality demonstrate a significantly greater ability to resolve cognitive conflict between perceptual and conceptual representations compared to students who follow a traditional lesson. Specifically, it is hypothesized that the experimental group will achieve higher scores on the learning assessment, reflecting improved inhibition of intuitive but conceptually incorrect responses and more effective access to abstract, scientifically accurate conceptual representations.

3.2 *Sample*

The study involved a total of 72 students attending a public upper secondary school in the Tuscany region of Italy, namely the “Bianciardi” Art High School in Grosseto. Participants were randomly assigned to either an experimental group ($n = 36$) or a control group ($n = 36$). The sample was drawn from four classes belonging to the Architecture and Fine Arts curricula, including two classes in the third year ($n = 32$) and two classes in the fourth year ($n = 40$).

With regard to gender, the sample comprised 28 male students (38.9%) and 44 female students (61.1%). Participants’ ages ranged between 16 and 19 years. Participation was entirely voluntary and no financial incentives were provided. Before the implementation of the experimental activities, informed consent was obtained from all students and, where required, from their parents or legal guardians. All procedures complied with ethical standards for educational research, and data handling adhered to current privacy and data protection regulations, guaranteeing full anonymisation of participants’ information.

3.3 *Tools and Method*

The intervention required students to independently engage with an educational topic that was not directly related to their field of study. The selection of the content was informed by a preliminary needs analysis, which revealed that neuroanatomical concepts, although seemingly concrete, are perceived by students as particularly challenging, especially in terms of understanding spatial relationships and consolidating conceptual knowledge. For this reason, the study of human brain anatomy was selected, as it represents a domain in which discrepancies between perceptual salience

and conceptual accuracy frequently emerge, making it particularly suitable for investigating cognitive conflict processes and for being supported through augmented reality (AR) visualisation.

In a preliminary phase, all participants were administered the Rey Word List Test (Carlesimo et al., 1996), a standardised neuropsychological instrument used to assess memory functioning. This procedure made it possible to exclude the presence of potential memory deficits within the sample. Subsequently, the autonomous learning phase typical of the flipped classroom model was simulated.

The control group (CG) studied the content using traditional printed materials, consisting of handouts containing the same images provided to the experimental group, but presented in a static, two-dimensional format (Fig. 1).

Figure 1. Printed material used by the Control Group



In contrast, the experimental group (EG) had access to AR-enriched content through a mobile application installed on students' personal devices. Students in the EG could interact with the digital models in two ways: by scanning the Merge Cube, a physical cube marked with visual patterns, or by activating the “world” mode, which projected three-dimensional content directly into the surrounding environment via the device's camera. The Merge Cube enabled the visualisation of three-dimensional brain models in augmented reality, integrating the virtual object with the real environment and allowing students to rotate, explore, and manipulate the model as if it were physically present in space (Fig. 2).

Figure 2. Interaction of the Experimental Group with the three-dimensional brain model via Merge Cube and augmented reality



At the end of the autonomous learning phase, all participants completed a content acquisition assessment designed not only to measure learning outcomes, but also

to elicit situations of cognitive conflict between perceptual and conceptual representations. The assessment consisted of two tasks administered without time constraints. The first task (Definition Task) included open-ended questions requiring students to define specific brain structures, thereby assessing free recall and the depth of conceptual understanding.

The second task (Multiple-Choice Task) consisted of multiple-choice questions with five response options. The items were intentionally designed to generate semantic-perceptual conflict: alongside the correct answer, the alternatives included options that were visually salient or semantically familiar but conceptually incorrect. Correct responses therefore required students to inhibit intuitive but misleading answers and to rely on abstract, rule-based scientific knowledge, engaging processes of conflict resolution and inhibitory control.

Statistical analyses were conducted using Jamovi software (version 2.6). To examine whether significant differences in performance emerged between the experimental and control groups across the two tasks, independent samples t-tests were performed.

3.4 Data Analysis and Results

Descriptive statistics for the scores obtained in the two tasks are reported in Table 1.

Table 1. Descriptive Statistics

	Condition	N	Missing	Mean	Median	SD	Minimum	Maximum
Definition_Task_Total	CG	36	0	1.00	1.00	0.894	0	3
	EG	36	0	3.50	4.00	1.028	1	4
MultipleChoice_Total	CG	36	0	2.89	3.00	1.617	0	5
	EG	36	0	3.72	4.00	1.427	1	5

In both tasks, the experimental group achieved higher mean and median values than the control group, indicating an overall trend toward better performance among students who engaged with augmented reality.

To graphically represent the distribution of scores across the two tasks, violin box plots were used (Figures 3 and 4).

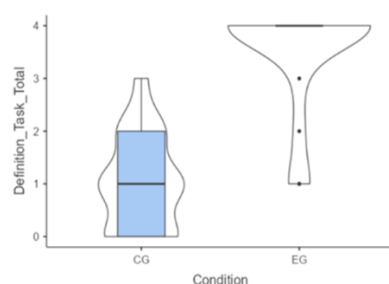


Figure 3.

Violin plot of the scores
Obtained in the Definition Task
By the control group (CG) and the
Experimentale Group (EG)

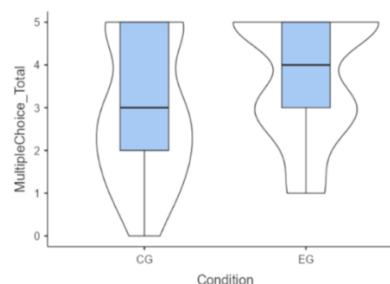


Figure 4.

Violin plot of the scores
obtained in the Multiple-Choice task
by the control group (CG)
and the experimental group (EG)

Specifically, in the Definition Task (Figure 3), the score distribution of the experimental group is strongly concentrated around the maximum value, with low variability. This pattern indicates a high and homogeneous level of performance, consistent with more effective construction and retrieval of stable conceptual representations. In the Multiple-Choice Task (Figure 4), the distribution appears more balanced but remains favourable to the experimental group, which shows a higher density of responses in the upper range of the scale and lower dispersion compared to the control group. This pattern suggests a more effective management of semantic-perceptual conflict situations, which required the inhibition of intuitive but conceptually incorrect responses.

The Shapiro–Wilk test revealed a significant violation of the normality assumption for all dependent variables ($p < .05$), as reported in Table 2.

Table 2. Results of the Shapiro–Wilk normality test for each dependent variable

	W	p
Definition_Task_Total	0.878	<.001
MultipleChoice_Total	0.915	<.001
Learning_Score_Total	0.892	<.001

However, the scientific literature highlights the robustness of the independent samples t-test even in the presence of moderate deviations from normality, provided that certain key conditions are met: approximately equal group sizes ($n = 36$ for each group), an overall sample size greater than 30 participants ($N = 72$), absence of extreme outliers, and homogeneity of variances. The latter assumption was confirmed

by Levene's test ($p > .05$ for all variables), as shown in Table 3 (Schmider et al., 2010; Blanca et al., 2017; Field, 2018).

Table 3. Results of Levene's Test for Homogeneity of Variances for each dependent variable

	F	df	df2	p
Definition_Task_Total	0.571	1	70	0.452
MultipleChoice_Total	0.150	1	70	0.700
Learning_Score_Total	0.377	1	70	0.541

Since all these conditions were satisfied, an independent samples t-test was performed (Table 4).

Table 4. Results of the independent samples t-tests comparing the experimental group (EG) and the control group (CG) on each learning task

		Statistic	df	p	Mean difference	SE difference		Effect Size
Definition_Task_Total	Student's t	-11.01	70.0	<.001	-2.500	0.227	Cohen's d	-2.594
MultipleChoice_Total	Student's t	-2.32	70.0	0.023	-0.833	0.359	Cohen's d	-0.546
Learning_Score_Total	Student's t	-6.90	70.0	<.001	-3.333	0.483	Cohen's d	-1.627

With regard to the Definition Task, the analysis revealed a statistically significant difference between the two groups [$t(70) = -11.01$, $p < .001$], with a mean difference of -2.50 and a very large effect size according to Cohen's d ($d = -2.594$). This result indicates that the use of augmented reality significantly enhanced the experimental group's ability to spontaneously retrieve correct definitions, suggesting a more robust conceptual representation and reduced interference from intuitive but incorrect responses.

In the Multiple-Choice Task, the analysis also showed a significant difference between the groups [$t(70) = -2.32$, $p = .023$], accompanied by a moderate effect size ($d = -0.546$). Given the structure of the task, this finding suggests that the experimental group managed cognitive conflict between perceptually salient options and conceptually correct responses more effectively, demonstrating a greater ability to inhibit intuitive but misleading answers.

Finally, with regard to overall learning performance (Learning_Score_Total), the t-test revealed a highly significant difference between the two groups [$t(70) = -6.90$, $p < .001$], with a large effect size ($d = -1.627$). Overall, the results allow for the rejection of the null hypothesis and support the research hypothesis, indicating that the integration of augmented reality within the flipped classroom model significantly im-

proved students' performance in both spontaneous and guided recall tasks, as well as in the management of cognitive conflict, with positive effects on overall learning outcomes.

4. Discussion

The present study investigated whether augmented reality (AR), implemented through the Merge Cube, supports more effective management of cognitive conflict between perceptual and conceptual representations in upper secondary school students. Overall, the results indicate a clear advantage for the experimental group across learning outcomes, including performance in tasks specifically designed to elicit semantic-perceptual conflict.

A parsimonious interpretation of the present findings is that AR exposure altered the conditions under which learners encountered and resolved representational competition. The results align with the conflict monitoring framework, in which conflict is conceived as the co-activation of competing representations or response tendencies, with control mechanisms biasing processing toward task-relevant information (Botvinick et al., 2001).

In this perspective, students in the AR condition may have been better positioned to suppress perceptually salient but conceptually incorrect options and select scientifically appropriate representations, consistent with models emphasizing cortical amplification of task-relevant information during conflict resolution (Egner & Hirsch, 2005).

More broadly, this interpretation is compatible with accounts that highlight multiple conflict-driven control mechanisms and adaptive adjustments following conflict experiences (Egner, 2008).

At the level of higher-order cognition, this also resonates with evidence that prefrontal networks are crucial for selecting among competing representations and supporting flexible relational reasoning (Krawczyk, 2012), a process that becomes especially relevant when intuitive responses must be inhibited to access abstract rule-based knowledge.

4.1 Two complementary mechanisms: conflict reduction vs. improved conflict management

Importantly, the present design does not allow a definitive disentanglement between two non-mutually exclusive mechanisms.

A first possibility is conflict reduction. AR may have provided more coherent perceptual information and more stable spatial relations, thus weakening the pull of misleading salience and reducing representational ambiguity. This interpretation is consistent with the notion of AR as a didactic mediator capable of bridging abstract concepts and concrete experience through exploratory and multisensory interaction (Martin et al., 2018), potentially supporting the construction of more stable mental models.

In this view, the advantage observed in the AR condition would reflect improved conceptual accessibility rather than a direct enhancement of inhibitory control.

A second, complementary possibility is improved conflict management. In this case, AR does not merely simplify the representational landscape; it may actively

engage executive functions by making discrepancies between intuition and scientific structure more explicit, thereby recruiting inhibitory control to suppress intuitive but incorrect responses. This mechanism is consistent with research explicitly integrating AR with cognitive conflict models in science learning, showing that AR-based conflict induction can function as a trigger for conceptual change and scientific literacy gains (Mufit & Dhanil, 2024; Dhanil & Mufit, 2025; Mufit et al., 2025).

The present findings extend this line of research to neuroanatomical content, suggesting that AR-supported exploration may contribute not only to knowledge acquisition but also to the processes required to manage competing representations.

The interpretation that AR interacts with inhibitory control is further supported by experimental work adopting classical conflict paradigms in augmented environments. Dempo et al. (2022), using an AR flanker-based design, demonstrated that AR presentation modalities modulate perceptual interference and attentional control demands, with measurable behavioural and electrophysiological signatures.

Although the present study did not include reaction-time indices or EEG measures, Dempo et al.'s findings provide convergent evidence that AR is not cognitively neutral: design features and presentation formats can increase or attenuate conflict, thereby shaping the extent to which control resources are required.

This convergence supports a cautious inference that the improved performance observed here plausibly reflects altered conflict dynamics rather than a purely motivational effect.

From a broader educational standpoint, the present results are consistent with evidence syntheses reporting positive effects of AR on learning outcomes, while also emphasizing that effects depend on instructional design and integration into pedagogical models (Akçayır & Akçayır, 2017; Garzón et al., 2019).

Recent scholarship further stresses that AR's potential goes beyond novelty, highlighting its role in attention regulation and deep engagement when the technology is pedagogically purposeful (Koumpouros, 2024).

In the present study, AR was embedded in a structured learning sequence and paired with an assessment purposely engineered to elicit semantic–perceptual conflict; this alignment likely contributed to the observed differences.

4.2 Limitations and future directions

Despite the robustness of the observed group differences, several limitations should be acknowledged, opening important directions for future research. First, the study relied primarily on accuracy-based performance measures, without including direct indices of executive functions, such as reaction times in Stroop or flanker tasks, or neurocognitive markers of conflict monitoring. Consequently, interpretations concerning inhibitory control and executive regulation remain inferential, grounded in well-established theoretical models but not directly verified at the neuropsychological level.

A second limitation concerns the difficulty of isolating which specific features of augmented reality are most influential for learning outcomes. Although tools such as the Merge Cube provide manipulable, embodied, and spatially stable 3D representations, the present design does not allow disentangling the relative contribution of interactivity, embodiment, spatial stability, or novelty effects. Previous research on the educational use of the Merge Cube highlights its feasibility and pedagogical potential,

while also pointing to the need for more articulated designs capable of analytically decomposing these dimensions (Ntuli, 2019; Voštinár & Ferianc, 2023). Future studies adopting factorial designs and integrating process measures—such as response times, confidence ratings, or delayed post-tests—would be particularly valuable in clarifying whether augmented reality primarily reduces the intensity of cognitive conflict or enhances learners' capacity to regulate and manage it.

5. Conclusions

The present study contributes to the growing body of research investigating the educational potential of augmented reality by focusing on its role in the management of cognitive conflict between perceptual and conceptual representations. Building on conflict monitoring frameworks (Botvinick et al., 2001; Egner & Hirsch, 2005), the findings suggest that AR-supported learning environments may influence how learners navigate competition between intuitively salient and conceptually accurate alternatives.

In line with previous studies integrating augmented reality and cognitive conflict-based learning (Mufit & Dhanil, 2024; Dhanil & Mufit, 2025), the results indicate that exposure to interactive three-dimensional representations is associated with improved performance in tasks requiring the inhibition of misleading perceptual cues. Rather than functioning solely as a motivational or illustrative tool, AR appears to operate as a didactic mediator, shaping the representational conditions under which cognitive conflict is experienced and resolved.

Importantly, the present findings align with experimental evidence showing that augmented environments can modulate perceptual interference and attentional control demands (Dempo et al., 2022), supporting the plausibility that AR interacts with executive processes involved in conflict resolution. At the same time, the study does not allow definitive conclusions regarding whether AR primarily reduces conflict intensity or enhances conflict management through inhibitory control. This distinction remains a critical direction for future research and highlights the need for designs incorporating direct measures of executive functioning.

From an educational perspective, the results reinforce conclusions drawn by recent reviews and meta-analyses indicating that the effectiveness of AR depends on its pedagogical integration rather than on novelty alone (Akçayır & Akçayır, 2017; Garzón et al., 2019). When embedded within learning activities explicitly designed to elicit and address cognitive conflict, AR may support deeper conceptual engagement, particularly in domains characterised by high representational complexity, such as neuroanatomy.

Overall, this study supports a view of augmented reality as a technology capable of contributing to learning not only by enhancing engagement, but also by interacting with core cognitive mechanisms underlying conceptual change. By situating AR within a cognitive conflict framework, the present work offers a theoretically grounded perspective that may inform future research and instructional design aimed at fostering meaningful learning through emerging educational technologies.

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