AUGMENTED REALITY AND FLIPPED CLASSROOM: THE ROLE OF THE MERGE CUBE AS A DIDACTIC MEDIATOR IN AUTONOMOUS LEARNING

REALTÀ AUMENTATA E FLIPPED CLASSROOM: IL RUOLO DEL MERGE CUBE COME MEDIATORE DIDATTICO NELLO STUDIO AUTONOMO

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ABSTRACT

The rapid development of digital technologies has profoundly transformed educational paradigms, opening new perspectives for innovative teaching methodologies within dynamic and inclusive learning environments. In this context, the present study explores the role of Augmented Reality (AR) as a didactic mediator in the autonomous learning phase of the flipped classroom model, with a specific focus on the use of the Merge Cube. The research, conducted with a sample of upper secondary school students, examined the impact of this innovative tool on the learning of abstract and complex educational content. The findings show that the Merge Cube fosters significantly higher performance, confirming the potential of AR to promote active, experiential, and personalised learning.

Il rapido sviluppo delle tecnologie digitali ha profondamente trasformato i paradigmi educativi, aprendo nuove prospettive a metodologie didattiche innovative all'interno di ambienti di apprendimento dinamici e inclusivi. In quest'ottica, il presente studio esplora il ruolo della Realtà Aumentata come mediatore didattico nello studio autonomo previsto dalla flipped classroom, con un focus specifico sull'utilizzo del Merge Cube. La ricerca, condotta su un campione di studenti della scuola secondaria di secondo grado, ha analizzato l'impatto di questo strumento innovativo sull'apprendimento di contenuti didattici astratti e complessi. I risultati evidenziano come il Merge Cube favorisca performance significativamente superiori, confermando il potenziale dell'AR nel promuovere un apprendimento attivo, esperienziale e personalizzato.

KEYWORDS

Innovative educational technologies; active learning methodologies; digital innovation; upper secondary school; digital learning
Tecnologie didattiche innovative; metodologie attive; innovazione digitale; scuola secondaria di secondo grado; apprendimento digitale.

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Introduction

In recent years, the educational landscape has undergone profound transformations, making it increasingly necessary to reconsider traditional teaching methodologies in light of the opportunities offered by digital technologies. Within this context, flipped learning has emerged as one of the most innovative and promising pedagogical strategies (Sánchez et al., 2019; Jeong et al., 2016). Its global diffusion and success across a variety of school and university settings are grounded in its ability to invert the conventional temporal and spatial dimensions of learning, positioning students as active and central participants in the educational process (O'Flaherty et al., 2015).

At the heart of the flipped learning model lies the principle of shifting content acquisition outside the classroom—often through audiovisual materials and digital resources—thus reserving in-person time for deeper exploration, collaborative work, and practical application (Baig et al., 2023; Elazab et al., 2015). This approach not only fosters student autonomy and self-reflection but also maximises the use of classroom time by transforming lessons into spaces for discussion and problem-solving (Abeysekera et al., 2015; Schmidt et al., 2016).

However, realising the full potential of flipped learning requires a continuous updating of pedagogical strategies and a conscious integration of advanced technologies. In this regard, Augmented Reality (AR) stands out as a powerful didactic mediator, capable of enriching content, enhancing motivation, and providing students with immersive and interactive learning experiences (Cabero et al., 2019). The integration of AR into the flipped classroom enables educators to bridge the gap between theoretical knowledge and practical application, creating dynamic, multisensory learning environments that promote the development of transversal skills such as critical thinking, creativity, and problem-solving abilities (Bacca et al., 2014; Diaz et al., 2018).

Against this backdrop, the present contribution aims to investigate the role of Augmented Reality as an innovative educational mediator within the flipped classroom model, with particular attention to its impact on learning effectiveness. The study involved a sample of upper secondary school students who, within a learning environment structured according to the principles of flipped learning, engaged with educational content enhanced by interactive AR models. The objective was to assess how the integration of innovative technologies can enhance students' deep understanding of concepts, fostering a more active, meaningful, and personalised learning experience. Drawing on a review of the scientific literature, this paper seeks to offer both theoretical insights and empirical findings to support the design of didactic units that respond to the evolving needs and characteristics of today's digital-native learners.

1. Augmented Reality as an educational mediator

Among the many opportunities offered by Information and Communication Technologies (ICT), Augmented Reality (AR) stands out as one of the most promising innovations of recent decades (Saidin et al., 2015), particularly within the educational sector, where it is progressively assuming a strategic and transformative role (Kesim & Ozarslan, 2012). Its ability to enrich the physical environment with interactive digital content allows for a redefinition of traditional teaching and learning approaches, offering immersive, dynamic, and highly engaging educational experiences (Cheng, 2017; Lembo et al., 2023; Cipollone et al., 2023; Lembo et al., 2024).

AR is defined as a technology that enables the real-time integration of digital information onto physical environments through various technological devices such as smartphones, tablets, and AR headsets (Elmqaddem, 2017). This technology not only expands access to complex educational content but also acts as a vehicle for creating supplementary multimedia resources that stimulate learning in a more multisensory and adaptive manner (Martin et al., 2018).

The adoption of augmented reality spans all stages of the educational journey: from early childhood education (López Belmonte et al., 2020), where it stimulates curiosity and cognitive play, to primary and secondary school and into higher education, where it allows for the exploration of abstract concepts through three-dimensional representations and interactive simulations (Lembo et al., 2024).

Key benefits associated with the use of AR in educational contexts include a significant increase in student engagement and a more autonomous and responsible participation in the learning process (Akçayır & Akçayır, 2017). Furthermore, AR contributes to the development of digital skills (Garzón et al., 2019), fosters intrinsic motivation (Bacca et al., 2014), and enhances learners' concentration and attention management (Koumpouros, 2024). The opportunity to explore content through discovery and experimentation promotes active learning based on collaborative and constructivist approaches (Cadavieco et al., 2017; Chen et al., 2017).

Augmented reality also offers effective responses to special educational needs through the personalisation of visual, auditory, and tactile stimuli, fostering inclusion and educational equity. The use of augmented environments promotes a positive learning climate, stimulates creativity, and makes the educational process more engaging and accessible to a wide range of cognitive profiles (Espinosa, 2015).

AR is steadily consolidating its role within the international educational landscape, emerging as one of the most widely adopted technologies and a growing focus within contemporary scientific literature (Akçayır & Akçayır, 2017). Ongoing empirical experimentation and rapid technological advancements continue to open new avenues for research and application, encouraging its systematic integration into innovative teaching models. Among these, the flipped classroom represents a particularly favourable context, in which AR acts as a pedagogical catalyst capable of facilitating experiential learning processes, promoting deep cognitive processing, and supporting the autonomous and meaningful construction of knowledge.

1.1 The Merge Cube in the flipped classroom

A concrete application of augmented reality (AR) in the educational field is represented by the Merge Cube, an innovative device that has revolutionised the interaction with three-dimensional digital content. Introduced to the market in 2017, the Merge Cube appears as a simple physical cube; however, when combined with mobile devices (smartphones or tablets) and dedicated applications, it transforms into an interactive holographic interface (Taufiq et al., 2021). By utilising the camera of a mobile device, the Merge Cube enables the projection of three-dimensional AR models directly onto the screen, visually integrating them with the surrounding physical environment (Ntuli, 2019). This interactive modality allows students to virtually manipulate complex objects, simulating their tangible presence within real space. The resulting educational experience is characterised by a high degree of immersiveness and engagement, facilitating the understanding of abstract structures—such as mathematical models, anatomical organs, historical artefacts, or astronomical representations—through a concrete, exploratory, and multisensory approach. As such, this technology represents a powerful pedagogical tool capable of fostering active learning and supporting the transfer of theoretical knowledge to applied contexts (Lin, 2021).

Recent scientific literature recognises the Merge Cube as an innovative teaching tool, capable of transforming the educational experience through immersive and interactive learning approaches (Voštinár et al., 2023; Cowin, 2020). The ability to visualise and manipulate three-dimensional AR objects enables students to explore abstract concepts in a tangible and concrete manner, promoting experiential and multisensory learning (Taufiq et al., 2021). Within the scope of the present study, the Merge Cube has been deliberately positioned as an advanced educational mediator. From this perspective, the Merge Cube proves to be a highly versatile tool, applicable across a broad spectrum of disciplinary domains. Its integration into educational processes facilitates the acquisition of complex knowledge and promotes the development of higher-order transversal skills such as problem-solving, critical thinking, and independent analytical abilities (Taufiq et al., 2021).

Due to its specific features, the integration of the Merge Cube into innovative pedagogical models, such as the flipped classroom, enhances curricular content through immersive and interactive learning experiences. It stimulates epistemic curiosity and fosters a high level of cognitive and emotional engagement among students. In this regard, the Merge Cube does not merely serve as a technological support; rather, it assumes the role of a cognitive facilitator and didactic mediator, effectively bridging theoretical knowledge and practical application. This synergy contributes to the creation of dynamic, inclusive, and personalised learning environments aligned with the principles of Universal Design for Learning (UDL) and the latest evidence from neuroscientific and educational research. The integration of the Merge Cube within the flipped classroom framework presents an extremely promising prospect: it enables students to engage with content autonomously and arrive in class already prepared for collaborative and application-based activities, where knowledge is transformed into active experience.

2. Research project

The present research project is situated within the framework of the flipped classroom model, in which students are first required to independently acquire disciplinary content outside the traditional classroom setting, thereby reserving in-class time for in-depth exploration, collaboration, and practical application. While this phase is typically supported by standard audiovisual materials and digital resources, this study adopts a more innovative approach by introducing Augmented Reality (AR) as a mediator within the individual learning process. The aim of the research is to investigate the impact of AR on the learning process of upper secondary students, with particular attention to their ability to understand, retain, and recall abstract and complex concepts.

2.1 Research hypotheses

The research hypothesis aims to determine whether the experimental group (EG), which engaged with instructional content enriched by augmented reality (AR) models during the independent study phase of the flipped classroom, achieves significantly different learning performance outcomes compared to the control group (CG), which followed traditional study methods.

The specific statistical hypotheses are as follows:

- H1a: there is a significant difference between the EG and the CG in the task assessing free recall of information (Definition Task).
- H1b: there is a significant difference between the EG and the CG in the task assessing cued recall of information (Multiple Choice Task).
- H1c: there is a significant difference between the EG and the CG in overall learning performance.

2.2 Sample

The research sample consists of 72 students enrolled in a public upper secondary education institute located in the Tuscany region of Italy, specifically the "Bianciardi" Art School in Grosseto. Participants were divided randomly into two groups of equal size: an experimental group (n = 36) and a control group (n = 36). The students came from four classes within the Architecture and Fine Arts tracks, including two third-year classes (n = 32) and two fourth-year classes (n = 40).
In terms of gender distribution, the sample included 28 male students (38.9%) and 44 female students (61.1%), as shown in Figure 1. Regarding age, participants ranged from 16 to 19 years old, with detailed distribution presented in Figure 2.

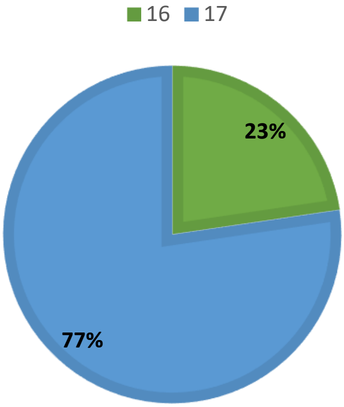

Figure 1. Gender distribution of the sample

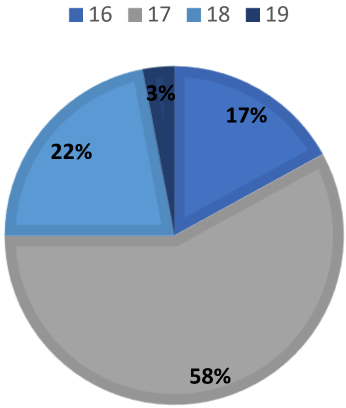

Figure 2. Age distribution of the sample

The composition of the sample reflects an ethnic diversity, with six students of mixed or foreign origin (Italo-Chilean, Italo-Polish, Italo-Romanian, Peruvian, Ukrainian, and Italo-Venezuelan). All other participants are of Italian nationality.

Concerning the educational profile, 25% of the sample held a Personalised Didactic Plan (PDP). No students with certified disabilities, as defined by Italian Law no. 104/1992, were present in the classes involved.

Participation in the study was voluntary and did not involve any form of financial compensation. Prior to the start of the experimental procedures, all participants, and where applicable, their parents or legal guardians, provided written informed consent, in accordance with ethical standards for research. Data processing was conducted in full compliance with current privacy and data protection regulations, ensuring the complete anonymisation of all collected information.

2.3 Tools and methods

The intervention required students to independently study an educational topic that was not directly related to their academic specialisation. The choice of content was guided by a preliminary needs analysis, which highlighted how neuroanatomical concepts—although concrete—are among the most difficult for the target school population to understand and memorise.

For this reason, the study of the anatomy of the human brain was selected, as it was considered particularly suitable for being supported by dynamic visualisation through augmented reality (AR).

In a preliminary phase, all participants were administered the Rey Word List Test (Carlesimo et al., 1996), a standardised neuropsychological assessment that allowed us to exclude the presence of any deficits in memory processes within the sample. Subsequently, the self-study phase typical of the flipped classroom model was simulated.

The control group (CG) studied the content using traditional printed materials, consisting of handouts that contained the same images provided to the experimental group, but presented in a static, two-dimensional format (Figure 3).

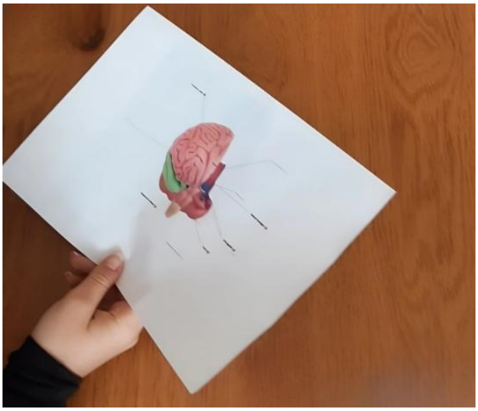

Figure 3. Printed material used by the Control Group

The experimental group (EG), by contrast, had access to AR-enriched content via a mobile application installed on each student's personal device. Students could interact with the digital models in two ways: by scanning the Merge Cube—a simple physical cube marked with visual patterns—or by activating the “world” mode, which projected the content directly into the surrounding environment through the device’s camera. The Merge Cube enabled the projection of three-dimensional models in AR onto the smartphone screen, visually and spatially integrating the virtual object with the real environment, as illustrated in Figure 4. This interactive modality allowed students to virtually manipulate the object, simulating its tangible presence in real space.

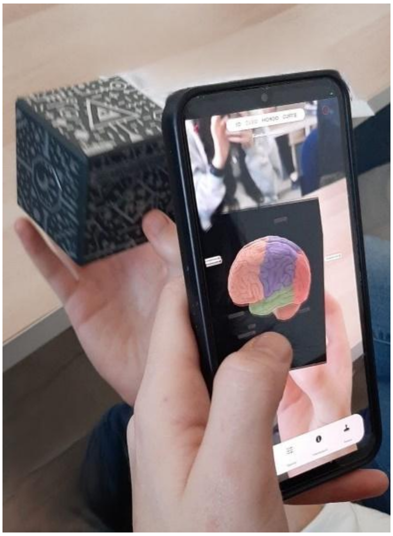

Figure 4. Interaction of the Experimental Group with the three-dimensional brain model via Merge Cube and augmented reality

At the end of the autonomous learning phase, all participants completed a content acquisition assessment questionnaire, composed of two tasks designed to measure memorisation, without time constraints. The first task (Definition Task), designed to test Hypothesis H1a, consisted of open-ended questions that required participants to define specific parts of the brain, thereby assessing their free recall ability. The second task (Multiple-Choice Task), developed to test Hypothesis H1b, included multiple-choice questions (each with five answer options), which required the functional identification of specific brain areas, thus assessing guided recall.

The statistical analysis was conducted using Jamovi software (version 2.6). To determine whether performance in the two tasks differed significantly between the experimental and control groups, an independent samples t-test was performed.

2.4 Data analysis and results

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

	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

Table 1.Descriptive Statistics

In both tasks, the experimental group achieved higher mean, and median scores compared to the control group, suggesting a general trend of better performance among participants who engaged with augmented reality.
To provide a graphical representation of the data distribution across the two tasks, violin box plots are shown in Figure 5 and Figure 6.

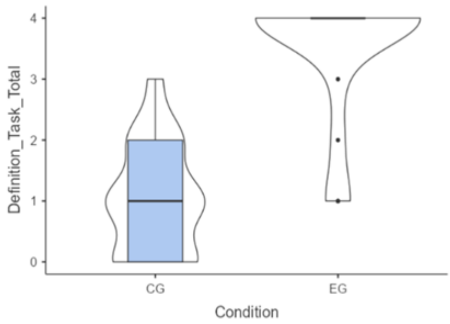

Figure 5. Violin plot of the scores obtained in the Definition Task by the Control Group (CG) and the Experimental Group (EG)

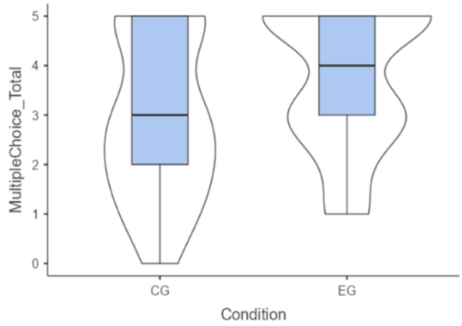

Figure 6. Violin plot of the scores obtained in the Multiple-Choice Task by the Control Group (CG) and the Experimental Group (EG)

Specifically, in the Definition Task (Figure 5), the distribution of the experimental group is highly concentrated around the maximum score, with low variability, indicating a uniform level of performance within the group. In the Multiple-Choice Task (Figure 6), the distribution appears more balanced but still 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.

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

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

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

However, the scientific literature highlights the robustness of the independent samples t-test in the presence of moderate violations of normality, provided that certain key conditions are met: the groups must have approximately equal sizes (in this case, both consist of 36 participants); the overall sample size must exceed 30 subjects ($N = 72$); no extreme outliers should be present; and the assumption of homogeneity of variances must be satisfied, as 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).

	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

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

Therefore, since all these criteria were met by the data collected in the present study, the independent samples t-test was conducted (Table 4).

		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

Note. H_a $\mu_{CG} \neq \mu_{EG}$

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

With regard to the Definition Task, corresponding to hypothesis H1a, the t-test 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). These results support hypothesis H1a and indicate that the use of augmented reality significantly enhanced the experimental group's ability to spontaneously recall definitions compared to the control group.

In the case of the Multiple-Choice Task, related to hypothesis H1b, the analysis also revealed a significant difference between the groups [t(70) = –2.32, p = .023], with a moderate effect size (d = –0.546). This suggests that guided recall was likewise facilitated by the augmented reality intervention, although with a less pronounced impact than in the previous task.

Finally, regarding overall learning performance (Learning_Score_Total), related to hypothesis H1c, the t-test showed a highly significant difference between the two groups [t(70) = –6.90, p < .001], accompanied by a large effect size (d = –1.627).

These findings allow for the rejection of all null hypotheses and the acceptance of the alternative hypotheses, confirming that the integration of augmented reality within the flipped classroom model significantly improved students' performance in both spontaneous and guided recall, as well as their overall learning outcomes.

3. Discussion

The present study aligns with recent research investigating the impact of immersive technologies within innovative pedagogical models, with a particular focus on the flipped classroom. This approach is based on the inversion of traditional learning times and spaces, assigning students the responsibility for acquiring content independently before the in-class activity, which then becomes an opportunity for discussion, reflection, and practical application (O'Flaherty et al., 2015; Baig et al., 2023). Within this framework, Augmented Reality (AR) – and particularly the Merge Cube – emerges as an effective educational mediator, capable of enhancing the comprehension of abstract concepts through multisensory and interactive experiences (Cabero et al., 2019; Lin, 2021).

The aim of this study was to examine the effectiveness of integrating AR during the independent study phase of a flipped classroom model, in a sample of upper secondary school students. The research hypotheses explored the impact of AR on spontaneous recall (H1a), guided recall (H1b), and overall learning performance (H1c), comparing the performance of the experimental group – who interacted with three-dimensional AR models – with that of the control group, who studied using static, two-dimensional paper-based materials.

The findings highlight the effectiveness of the intervention: the experimental group achieved significantly higher performance across all variables considered. In particular, the spontaneous recall task (Definition Task) was highly sensitive to the AR intervention, suggesting that active interaction with digital models facilitated deeper and more durable encoding of information. Although the effect was less pronounced in the guided recall task (Multiple-Choice Task), the experimental group still showed superior performance, indicating a positive influence of AR in supporting guided retrieval of information. Finally, overall learning performance was significantly higher among students in the experimental group, confirming the added value of immersive technology in the context of autonomous study.

These results are consistent with the most recent scientific literature, which attributes a key role to Augmented Reality in fostering active and meaningful learning (Voštinár et al., 2023; Cowin, 2020). In particular, the use of the Merge Cube appeared to facilitate the construction of more stable and accessible mental representations, allowing students to retrieve learned information more effectively. The opportunity to explore and manipulate digital content in three dimensions, observing it from multiple angles, appears to have supported both comprehension and retention of the complex concepts presented during the autonomous learning phase.

Conclusions

This study contributes to the ongoing debate on the integration of immersive technologies within contemporary pedagogical models, highlighting the role of Augmented Reality (AR) as a didactic mediator in the flipped classroom. The inclusion of the Merge Cube in the autonomous learning phase demonstrated how interactive digital tools can effectively support the acquisition of complex content.

In particular, the ability to manipulate three-dimensional objects, access content from different angles, and integrate visual and spatial stimuli facilitated the construction of more stable mental representations, which proved beneficial for both comprehension and retention. In this context, AR emerges as a mediator capable of translating abstract concepts into concrete experiences, enriching the learning environment and enhancing its overall effectiveness.

The experimental evidence collected suggests that future instructional design may benefit from a conscious and pedagogically grounded use of Augmented Reality, aimed at strengthening students' autonomy and competence within increasingly hybrid and flexible educational contexts.

Author contributions

The contribution represents the result of a collaborative effort among the authors. Specifically, Elisabetta Tombolini is author of § 2, 3 & Conclusion; Luna Lembo is author of Introduction & § 1; Francesco Peluso Cassese supervised the research project.

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