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Visual Learning and Social Impact Assessment: Experimentation and Analysis of Outcomes in the School Context †

Vincenzo Nunzio Scalcione

Department for Humanistic, Scientific and Social Innovation (DIUSS), University of Basilicata, 85100 Matera, Italy; vincenzo.scalcione@unibas.it

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Abstract

How can we assess the social impact of visual learning technologies in educational environments? This question guides the present study, which proposes a social impact assessment (SIA) framework designed to capture not only the cognitive efficacy of digital tools, but also their implications in terms of equity and participation. The research is founded on a quasi-experimental study conducted in two secondary schools. The methodological approach integrated quantitative measurements, employing a pre-test/post-test design with control groups, alongside qualitative methods through structured observations and focus groups. Data indicate significant improvements in content comprehension (+18%, d = 0.72, 95% CI [0.58; 0.86]) and motivation, while simultaneously revealing concerning disparities: students with personal devices at home achieve 15% higher results in visuo-spatial tasks, while nearly one-third of the sample demonstrates deficiencies in basic digital competencies that limit their benefits.

Keywords: visual learning; educational technology; social impact assessment; educational equity; digital divide

1. Introduction

Visual learning technologies represent one of the most significant innovations in contemporary educational practice [1]. Interactive visualizations, immersive simulations, and augmented reality environments: tools that only years ago belonged to science fiction now inhabit our schools, promising to radically transform the way students learn.

In general educational practice, and in school settings in particular, the adoption of such tools has become increasingly frequent. The situation that emerges, however, does not always correspond to expectations; the implementation of educational technologies can lead to differentiated outcomes among groups of students, engendering new forms of inequality [2]. This creates an operational modality that, even if motivated by sound educational intentions, can in fact reinforce preexisting dysfunctional behaviors, generating an atmosphere of disorientation.

It should be noted that psycho-cognitive research has thoroughly investigated the mechanisms through which visual representations facilitate learning. Dual coding theory [3] and cognitive load studies [4,5] have provided solid foundations for understanding how the brain processes information presented in visual format. This perspective, while valuable, captures only part of the phenomenon: educational technologies do not operate in a vacuum, but rather are embedded in contexts traversed by preexisting inequalities.

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Within the articulated structure of the intervention framework outlined, the teacher, from the perspective of an inclusive culture, must not shy away from assuming a self-formative and self-transformative nature, accepting the challenge of the existing complexity, in order to promote new capabilities [6,7]. In accordance with the principles of inclusion, it is therefore necessary to implement personalized didactic proposals [8] that give due consideration to knowledge, policies, strategies, and inclusive best practices to be realized following careful analysis of "special" and other educational needs emerging within the school and social context, so as to work toward removing the logic of containment, paternalism, and micro- and macro-exclusions and marginalization.

Adequate theoretical reflection cannot elude the contribution of the critical tradition. Freire [9] distinguished between "banking" education, where knowledge is deposited in passive students, and problem-posing education that develops critical consciousness. Adorno and Horkheimer [10], in their Dialectic of Enlightenment, clearly grasped how technical progress carries within it an ambivalent dialectic: the promise of emancipation can reverse into its opposite, generating new forms of domination through standardization logic.

2. Innovative Evaluation Tools: Social Impact Assessment

Within such a framework, social impact assessment (SIA) presents itself as a systematic methodology for examining the consequences of interventions on individuals, communities, and institutions [11,12]. This approach bases its theoretical foundations in territorial and environmental planning, offering conceptual and operational tools to overcome the limitations of traditional evaluations, too often focused exclusively on individual cognitive outcomes.

Unlike traditional evaluations centered on efficacy, SIA broadens the perspective to include unintended effects, distributive consequences, and transformations of social relations. Its guiding principles include involvement of affected populations, attention to distributive consequences, and consideration of effects in the short, medium, and long term. Several reasons converge in making the adoption of this approach urgent: didactic interventions never produce uniform consequences.

Educational technologies, from the perspective of the Social Construction of Technology [13], are not mere transmission instruments: they are socio-technical systems embedded in institutional, cultural, and economic contexts. Their effects emerge from the interaction between technical characteristics and social practices, and cannot be deduced from the properties of artifacts alone.

Research on the digital divide [14] has documented the multiple stratifications that traverse the access to and use of technologies. A first issue concerns physical access: who possesses devices and connectivity, who lacks them. Even in the presence of material access, disparities persist in the ability to use tools effectively. There is then a more subtle level, regarding the differential capacity to convert digital engagement into tangible advantages: academic results, professional opportunities, and civic participation.

The post-phenomenology of Ihde [15,16] has developed a particularly fertile framework for analyzing the relationship between human beings and technological artifacts. A key concept is "multistability": the same technology can stabilize in different configurations depending on contexts of use. Ihde identifies a characteristic structure in which amplification and reduction always proceed together: visual learning technologies amplify the capacity to represent dynamic processes, while they may reduce embodied engagement and direct material exploration. This perspective invites us to resist both naive techno-enthusiasm and Luddite pessimism.

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From an Environment to Educational Context: Adapting the Sia Framework

The transfer of SIA from its original domain of territorial and environmental planning to the educational context requires an adaptation that cannot be taken for granted. In its classical formulation [12], SIA is articulated around categories such as: modifications of demographic structures, transformations of community networks, alterations of economic livelihood patterns, impacts on health and psychosocial wellbeing, and effects on cultural and heritage resources. Such categories, designed to evaluate large-scale infrastructure interventions (dams, highways, industrial plants), require semantic and operational reconfiguration to be applicable to the analysis of didactic interventions.

The present study proposes an adaptation founded on three assumptions. First, the school class is conceptualized as a micro-community endowed with relational dynamics, informal hierarchies, and shared practices analogous, despite their different scale, to those of territorial communities subject to traditional SIA. Second, the introduction of educational technologies is treated as an exogenous intervention that modifies the preexisting ecosystem, producing both intended and unintended effects and benefits and costs distributed potentially unequally among community members. Third, it is assumed that intervention effects manifest themselves at multiple levels (individual, interpersonal, institutional), requiring diversified measurement tools.

Starting from these assumptions, the SIA framework has been reconfigured into three indicator domains, each operationally translating the original categories into the lexicon and practices of educational research.

The practical applicability of the proposed SIA framework is configured through multiple operational levels that make it accessible and usable by educators and educational policymakers. At the micro level, teachers can employ the indicators of the "social inclusion" domain to monitor daily participatory dynamics in the classroom, identifying early situations of exclusion or marginalization related to technology use. Structured observations of a sense of belonging and collaborative patterns provide immediate feedback that informs timely pedagogical adjustments—for example, reorganizing work groups when hierarchies based on digital competence emerge, or providing individualized support to students who manifest technological anxiety. At the meso-institutional level, school principals and educational coordinators can use the SIA framework for quarterly formative assessments that guide decisions on resource allocation (for example, identifying needs for additional technical support or loaner devices), design of teacher professional development interventions (when gaps between technical and pedagogical competencies emerge), and adaptation of technology-use policies (when data reveal systemic barriers to equitable access). At the macro-political level, policymakers can employ the framework for ex ante impact assessments of investments in educational technologies, anticipating distributive consequences and designing compensatory measures (for example, providing allocations for home connectivity when demographic data indicate significant percentages of families without internet access), and for ex post accountability that verifies whether technological innovations financed with public funds have actually reduced rather than amplified educational inequalities.

The first domain, cognitive performance, corresponds to the dimension of impacts on "human capital" in traditional SIA, articulated in terms of school learning. The selected indicators include: (a) conceptual understanding, measured through structured tests with closed and open-ended responses, constructed from the foundational core concepts of the scientific disciplines involved in the intervention; (b) visuo-spatial reasoning, evaluated through standardized tests of mental rotation and spatial visualization (Italian adaptation of the Purdue Spatial Visualization Test); (c) problem solving, detected through authentic tasks that require integrated application of knowledge and procedures. The choice of

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these three indicators responds to the need to capture both the domain-specific (conceptual understanding) and transversal (visuo-spatial reasoning, problem-solving) effects of visual learning technologies.

The second domain, social inclusion, translates the category of impacts on "community networks and social cohesion." In the school context, this dimension has been operationalized through: (a) sense of belonging to the class, measured through a 5-point Likert scale (Italian adaptation of Goodenow's Psychological Sense of School Membership [17]); (b) perception of digital self-efficacy, detected with a questionnaire constructed ad hoc based on the DigComp 2.1 framework [18]; (c) quality of peer interactions during technological activities, documented through structured observation grids that record frequency and typology of collaborative exchanges. The detection of this domain aims to verify whether the introduction of technologies strengthens or weakens preexisting social bonds and whether it produces new forms of inclusion or exclusion.

The third domain (Table 1), community participation, adopts the category of impacts on "participation in decision-making processes" proper to environmental SIA, adapting it to the classroom context as a learning community. Indicators include: (a) level of active participation in didactic activities, detected through logs of digital platforms (access frequency, uploaded contributions, forum interactions) and classroom observations; (b) distribution of roles in collaborative activities, documented through analysis of group dynamics during work with visual technologies; (c) students' perception of voice and agency, explored qualitatively in focus groups. This domain intends to verify whether technologies favor widespread participation or whether, conversely, they produce a concentration of power and marginalization of some members of the class community.

Table 1. Summarizes the correspondence between categories of traditional SIA and the indicators adopted in the present study.

Traditional SIA Category	Educational Domain	Indicators
Impacts on human capital	Cognitive Performance	Conceptual understanding; visuo-spatial reasoning; problem solving
Community networks and social cohesion	Social Inclusion	Sense of belonging; digital self-efficacy; quality of peer interactions
Participation in decision-making processes	Community Participation	Active participation; distribution of roles; perception of voice and agency

It is appropriate to make explicit the limitations of such an adaptation operation. Some categories of traditional SIA do not find direct correspondence in the school context: economic and occupational impacts, for example, are detectable only in the long term and through longitudinal studies that fall outside the temporal horizon of the present research. Similarly, effects on cultural and heritage resources, central to environmental SIA, assume a different valence in the educational context, reducible rather to the transmission of disciplinary cultural heritage, a dimension that the present study did not intend to investigate directly. These limitations circumscribe the scope of the proposed framework, which does not purport to exhaust all dimensions of the social impact of educational technologies, but rather to offer an operational tool for the dimensions most immediately detectable in the school context.

The present study thus proposes a synthesis of the theoretical traditions invoked. Visual learning technologies are conceptualized as socio-technical systems whose impacts manifest at multiple levels: individual cognitive, interpersonal, institutional, and community levels. The SIA framework translates this perspective into three indicator domains: cognitive performance, social inclusion, and community participation. Each domain is evaluated through quantitative metrics and qualitative inquiry, with attention to dimensions of equity.

3. Methodology of the Didactic Experimentation

3.1. Research Design

The research adopted a mixed-methods approach, integrating quantitative and qualitative components according to a convergent design [19]. This choice responds to the need to capture both the magnitude of the effects and the underlying processes and meanings. The combination of different methods allows compensation for the limitations of each approach.

The quantitative component employed a quasi-experimental design with a non-equivalent control group and pre-test/post-test measurements. Randomization at the class level, rather than of individual students, respected organizational constraints and ethical concerns. The qualitative component included structured observations, focus groups with students, and semi-structured interviews with teachers.

3.2. Context and Participants

Participants: Students from two secondary schools, selected to represent differentiated contexts took part in the study: one school located in a medium-sized urban center, the other in a rural area.

Context analysis: The southern Italian context presents relevant specificities such as a more marked territorial digital divide compared to the national average, fragile socioeconomic fabric in some inland areas, and at the same time, a tradition of didactic experimentation linked to special programs. These characteristics, while enriching the study with significant contextual elements, also limit its generalizability. With respect to the characteristics of the treated group, there are differentiated levels of digital literacy and heterogeneous conditions of domestic technological access.

The two schools selected for the study present differentiated socioeconomic profiles representative of the diverse social contexts found in southern Italy. The first school, located in a medium-sized urban center, serves a user base characterized by predominantly middle-class families, with parents employed in the public sector, commerce, and liberal professions. A total of 68% of students have personal devices (tablets or laptops) at home, and 72% have access to high-speed internet connectivity. The educational level of parents is on average high: 45% hold at least a university degree, 38% a secondary-school diploma. The school has modern technological infrastructure, including two computer laboratories with 25 workstations each, interactive whiteboards in all classrooms, and a stable wifi connection. The second school, located in a mountainous rural area, presents a more fragile socioeconomic picture. A total of 42% of students come from families with occupations predominantly in the primary sector (agriculture, livestock) or in small local artisan and commercial activities. Only 35% of students have personal devices at home, and 28% report connectivity problems (absent connection or limited to mobile networks with discontinuous coverage in mountainous areas). The educational level of parents is on average lower: 18% hold a university degree, 52% a secondary-school diploma, 30% a middle-school license. The school infrastructure presents greater limitations: a single computer laboratory with 15 workstations, interactive whiteboards present in only four out of 12 classrooms, and unstable wifi connection due to limited-bandwidth problems in the geographic area. This contextual differentiation allowed observation of how infrastructural and socioeconomic disparities differentially influence the effectiveness of technological

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intervention, empirically confirming the theoretical hypotheses on the multilevel digital divide articulated in the conceptual framework of the study.

A total of 180 students between 14 and 18 years of age participated, distributed across eight classes (four experimental, four control). The sample presents balanced composition by gender (52% female, 48% male) and includes students with diverse socioeconomic backgrounds. Eight percent presented certified special educational needs.

3.3. Intervention and Instruments

Timeline and spaces: The intervention was structured from October to May 2023–2024, with activities conducted in school classrooms and computer laboratories throughout the entire academic year.

Methodology: In experimental classes, teachers integrated visual learning technologies in scientific disciplines, employing a cognitive–behavioral methodology designed to promote inclusive didactics. The tools used include mathematical visualization software, physics simulations, augmented reality applications for anatomy and biology, and collaborative platforms for concept mapping. All activities were conducted stimulating meaningful learning, cooperative learning, and utilizing a multiplicity of languages and tools. Teachers participated in 20 h of preliminary training and received continuous support. Control classes followed the ordinary curriculum.

Human and material resources: Human resources engaged in the project were curriculum teachers, previously trained in the use of visual learning technologies by external figures, who then autonomously implemented the activities. Material resources: digital devices, educational software, interactive whiteboards, and standardized assessment instruments.

Cognitive performance was evaluated with standardized tests of conceptual understanding, visuo-spatial reasoning tests, and problem-solving tasks, instruments validated on a pilot sample (n = 40). Digital literacy was detected with a questionnaire inspired by DigComp 2.1 [18]. Social dimensions were explored through a sense-of-belonging questionnaire, self-efficacy scales, and digital-platform logs. Focus groups deepened perceptions and experiences.

Quantitative analysis employed multiple regression controlling for baseline characteristics. Moderation analyses examined variations in effects across subgroups. The qualitative data were analyzed with a thematic approach [20], inductively coding transcriptions. Integration followed triangulation logic.

4. Results and Discussion

In secondary school, evaluation means knowing and understanding the levels reached by each student to identify the processes to promote, to favor the maturation and development of the learner. From this perspective, evaluation presents itself as an indispensable process for reflecting on the educational context and educational action.

Thus, the evaluations carried out by teachers were based on active observation, which allowed proposing diversified activities; at the end of the activities, teachers proceeded to complete standardized instruments, verifying significant improvements in cognitive performance and variations in relational dynamics.

Students in the experimental group show an average improvement of 18% (SD = 8.2) in conceptual understanding tests, which is statistically significant ($p < 0.001$, d = 0.72, 95% CI [0.58; 0.86]). In visuo-spatial tasks the improvement reaches 22% (d = 0.85, 95% CI [0.70; 1.00]); in problem-solving tasks the improvement is 20% (d = 0.78, 95% CI [0.63; 0.93]).

Table 2 synthesizes the main quantitative results of the intervention, presenting pre-test and post-test scores, percentage improvements, effect sizes (Cohen's d), and 95%

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confidence intervals for each cognitive dimension assessed. The data confirm the significant effectiveness of the visual learning intervention across all measured dimensions, with effects ranging from medium (conceptual comprehension) to large (visuo-spatial reasoning and problem-solving).

Table 2. Summary of quantitative results of the visual learning intervention: pre-test/post-test comparison for cognitive dimensions (N = 180). SD = standard deviation; CI = confidence interval.

Cognitive Dimension	Pre-Test Mean (SD)	Post-Test Mean (SD)	Improvement %	*p*-Value	Cohen's d	95% CI
Conceptual comprehension	68.4 (12.3)	80.7 (10.8)	+18%	<0.001	0.72	[0.58; 0.86]
Visuo-spatial reasoning	62.1 (14.5)	75.8 (12.2)	+22%	<0.001	0.98	[0.82; 1.14]
Visual problem-solving	58.3 (13.8)	69.9 (11.6)	+20%	<0.001	0.89	[0.73; 1.05]
Transfer tasks	55.2 (15.1)	68.7 (13.3)	+24%	<0.001	0.93	[0.77; 1.09]
Metacognitive awareness	51.7 (12.4)	61.3 (10.9)	+19%	<0.01	0.81	[0.65; 0.97]

These results were also observed in the family context, as emerges from questionnaires completed by parents; furthermore, the program also had a positive impact in the domain of higher cognitive processes. These aggregated data, however, conceal considerable variability. Analysis by subgroups reveals systematic differences linked to starting conditions. Those who had personal devices at home showed gains of 23% (SD = 7.1), those who had to share them or did not possess them showed 13% improvement (SD = 9.4): a 15% gap that is statistically significant ($p < 0.01$).

The baseline assessment revealed that 28% of students (n = 50) presented significant deficiencies in digital literacy: difficulties in navigation, file management, and resolution of elementary technical problems. This finding refutes the myth of "digital natives" [21] and confirms that exposure to technology does not guarantee adequate operational competencies. The subgroup with low digital literacy obtained halved benefits: 12% (SD = 10.1) compared to 21% (SD = 6.8) for those possessing adequate competencies.

Focus groups illuminated the underlying mechanisms. Students with low digital literacy reported spending considerable time struggling with technical difficulties, subtracting cognitive resources from content processing. One student recounted that "While others were already working on the simulation, I was still trying to figure out how to make the program work." Another: "I was ashamed to ask for help, so I pretended to follow along." The result is consistent with cognitive load theory.

Classroom observations documented complex dynamics. In some classes, informal hierarchies based on digital competence formed: more experienced students assumed leadership roles, relegating less able peers to marginal functions. A teacher observed that "Technical 'experts' automatically formed in the class and everyone turned to them, which somewhat unbalanced participation" [22,23].

On the other hand, unexpected positive dynamics also emerged. Some students with traditional learning difficulties found in visual activities a mode of expression more congenial to them. A student with dyscalculia reported that "With maps and simulations I can understand things that previously seemed impossible to me." Visual representations facilitated communication among students of different linguistic backgrounds, offering a shared language independent of mastery of Italian.

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Targeted and systematic observation allowed conferring value on the activated educational processes (dialogs, attitudes, participation, laboratory activities) [24]; the evaluations expressed were articulated respecting needs, aptitudes, and personal characteristics, contributing to defining a continuous formative process [25], conscious of the importance of preparing project paths that enable students to autonomously achieve their own acquisitions.

The entire program was conducted at measured learning rhythms; students demonstrated interest and participation toward the proposed activities, interacting with each other and collaborating in the implementation of didactic activities presented in the various project phases. Sense of belonging increased overall, with significant differences: already-integrated students recorded +12%, but those starting from lower levels only +5%. Technology seems to have amplified preexisting differences also on the relational plane.

The three-domain framework proved adequate to capture the dimensions of impact. Correlation analysis confirms that the domains, while interrelated, measure distinct aspects (r between 0.35 and 0.48). It should be noted that this is a first trial of the framework, not a definitive validation: data on predictive validity and replicability in different contexts are lacking.

While the variety of proposals and activities proved particularly motivating for students, teachers encountered a positive effect also with respect to the management of relational dynamics and the maturation of the concept of self. At the same time, there were some critical elements in the implementation phases: consider some activities whose structuring sometimes necessitated low rhythms in actual participation, or the effort required to integrate the formative proposal with stimulating activities for all students.

5. Conclusions

The central finding of this research configures an implementation paradox: visual learning technologies produce real benefits while distributing them unequally. Every decision about implementing educational technologies produces distributive consequences that advantage some and potentially disadvantage others. Focusing exclusively on average efficacy means, in fact, evading the responsibility to govern innovation justly [26].

This is not about rejecting technology: the documented benefits are real. It is about adopting them with an awareness of ambivalences. Equity must become an explicit evaluation criterion. The present study shows that social impact assessment frameworks can be adapted to educational contexts, offering methodologies to examine cognitive, social, and participatory consequences.

Responsibility proves shared. Educational institutions must implement technologies with support systems that prevent distorting effects [27]. Developers must incorporate considerations of accessibility and equity from the design phase onward. Researchers must expand evaluative paradigms including distributional analysis. Policymakers must establish accountability criteria that ensure public investments serve all students.

Further experimentation should be considered in order to verify the lasting effects of the aforementioned instrument. Future directions include longitudinal extension to evaluate the persistence of effects and evolutionary trajectories. It would be valuable to examine the efficacy of explicitly designed compensatory interventions: intensive digital literacy, peer tutoring, and personalized supports.

It is useful, in this regard, to recall how "attention, care, and consideration are at the basis of every relationship and in the case of the educational relationship, become of paramount importance" ([28], p. 164): only within a school community founded on these premises will learners be given the opportunity to understand that there is always

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an alternative, capable of conferring "the mark of a significant passage and expressing the irreplaceability of a presence".

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