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Beyond the traditional classroom: innovation and inclusion in math teaching with AI

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Abstract: Artificial Intelligence (AI) is emerging as a transformative technology for education, promising novel perspectives for personalized, inclusive, and effective pedagogy. Leveraging AI's capacity for data management and personalized learning pathways, this study focuses on teaching mathematics in primary school. Despite being crucial for the development of logical thinking, this discipline is often hampered by the abstract nature of foundational concepts (point, line, number) and the limitations of static traditional methods. AI presents itself as an innovative solution to overcome these challenges, utilizing advanced models like Deep Neural Networks and Generative Adversarial Networks (GANs) to create dynamic and interactive visualizations. Such tools make mathematical concepts more accessible, acting as a bridge between abstraction and students' cognitive processes. AI can monitor progress in real-time, providing personalized support that enhances teaching effectiveness and self-esteem. Crucially, it also holds immense potential for supporting students with disabilities, ensuring equitable and integrated access to content. To evaluate this efficacy, a quasi-experimental pilot study will be conducted in a third-grade primary class in Puglia, Italy, with a sample of approximately 20 students, including pupils with Special Educational Needs. The experiment is structured in three phases: teacher training, didactic intervention using AI tools (progressive visualizations and interactive environments), and evaluation via pre- and post-intervention tests.

Keywords: artificial intelligence; pedagogy; mathematics

1. Introduction

Artificial Intelligence is instigating profound systemic shifts across society, obliging the educational sector to harness its potential for didactic optimization and inclusivity. The core promise of AI lies in its ability to manage and analyze vast learning data, enabling the construction of dynamic educational experiences highly sensitive to the cognitive specificities of each learner. This data-driven approach establishes the foundation for genuine personalized learning, where content delivery and pace are modulated in real-time to address individual needs and knowledge gaps, proving more effective than traditional methods (Hwang et al., 2020). In compulsory education, primary school mathematics is a fundamental discipline, critical for holistic cognitive development and a strong predictor of future socioeconomic success. Despite this significance, the subject is challenged by persistent difficulties: young students often struggle to internalize abstract concepts (such as number sense or geometric entities) due to their complex nature and the limitations of static, symbol-based traditional teaching. These conventional methods often fail to bridge the gap between concrete experience and formal mathematical representation, leading to rote memorization rather than deep conceptual understanding. AI emerges as a disruptive solution to this problem, acting as an accelerator of conceptual acquisition through dynamic and interactive visualization. By leveraging advanced algorithms, AI systems can generate real-time visual and spatial representations, effectively making the abstract tangible. This interactive capability enhances conceptual comprehension by promoting the construction of robust mental schemas, transforming the student into an active explorer. Furthermore, AI excels at facilitating the translation between semiotic registers (numerical, graphical, symbolic), providing dynamic visual aids that explicitly connect these representations (Walkington & Popescu, 2020). Ultimately, this advanced visual adaptability strengthens inclusivity by allowing AI systems to instantaneously identify cognitive difficulties and modify representations to align with specific learning needs, including those of students with disabilities.

2. Materials and Methods

2.1 Research objective and question

The primary objective of this study is to explore how Artificial Intelligence can be utilized to foster both innovation and inclusion in the teaching of mathematics. Mathematics, perhaps more than any other subject, is characterized by a high level of abstraction that often represents a barrier for many students. This barrier becomes even more evident for those with special educational needs, who may struggle to connect abstract concepts with concrete representations. In this context, the integration of AI has the potential to act as a powerful mediator between abstraction and understanding. Our work focuses specifically on the use of Generative Adversarial Networks (GANs) as a means to produce visualizations and representations of mathematical concepts that are traditionally considered difficult to grasp. The guiding questions that shape our research are the following: does the integration of AI-generated images contribute to a more effective understanding of abstract mathematical concepts? And more importantly, can these tools foster greater inclusion by providing additional support to students with special educational needs? The contribution of this research lies in several aspects. First, we explore an innovative methodological approach by employing GANs in an educational setting, investigating how generative models can become allies of teachers in translating abstract concepts into meaningful visual experiences. Second, we aim to highlight the educational value of AI in making mathematics more accessible, not only by facilitating comprehension but also by reducing the cognitive barriers that often prevent students from actively engaging with the subject. Finally, the study seeks to provide concrete insights into how AI can be effectively integrated into everyday teaching practices, providing evidence that can guide educators and institutions in designing more inclusive and engaging learning environments.

2.2 Theoretical framework

The effectiveness debate in mathematics education has been significantly informed by neurodidactics, which aims to redefine didactic practices based on the neural mechanisms of learning and information consolidation (Lucangeli et al., 2018). Neurosciences confirm that learning is a dynamic process driven by neuroplasticity—the brain's capacity to reorganize connections in response to experience (Hwang et al., 2020). This is particularly relevant for mathematics, where the innate existence of "number sense" suggests that mathematical comprehension is fundamentally grounded in quantity processing, making it less purely abstract than often assumed (Dehaene, 2011). Central to this revised pedagogy is embodied cognition, which posits that the brain constructs meaning through bodily interaction and movement. Transforming an abstract concept into a sensori-motor experience enables the formation of robust, three-dimensional mental schemas that bridge the concrete and the symbolic. Conversely, traditional methods, being static and heavily symbolic, decontextualize mathematical knowledge and prematurely force the brain into purely abstract work, often failing to establish crucial connections with spatial and motor cognitive areas. Therefore, the introduction of tools providing dynamic visual and sensory interactivity aligns perfectly with neuroscientific findings. Dynamic visualizations go beyond mere display; they facilitate interaction and manipulation, offering immediate, multi-sensorial feedback crucial for mnemonic consolidation and the development of intuitive mathematical problem-solving skills (Walkington & Popescu, 2020). Artificial Neural Networks (ANNs) are computational models inspired by the human brain, composed of interconnected neurons that process inputs through weighted sums and activation functions to capture complex patterns. The simplest type, Feedforward Neural Networks (FNNs), transmit information in a single direction and are suited for static tasks like regression or classification. For sequential data, Recurrent Neural Networks (RNNs) introduce feedback connections to retain temporal information, but training them is challenging due to vanishing or exploding gradients. Long Short-Term Memory (LSTM) networks address this by regulating information flow through specialized gates, improving the modeling of long-term dependencies. While RNNs and LSTMs focus on prediction from past data, generative models extend deep learning to the creation of new data. Formulated within a probabilistic framework inspired by Bayes' theorem, these models aim to learn the underlying data distribution and generate realistic samples. Among them, Generative Adversarial Networks (GANs) use an adversarial mechanism to produce synthetic data that closely resemble real observations. The shift from RNN-LSTM architectures to GANs represents a paradigm change: from remembering and forecasting past information to creating new, plausible representations. In educational contexts, this enables the generation of intuitive and interactive visualizations of mathematical concepts, supporting both understanding and inclusion. In the context of mathematics teaching, GANs can be employed to generate images and visual representations that make abstract concepts more concrete and accessible, particularly for younger learners in primary school. These models can autonomously create examples, illustrations, and even dynamic visualizations that support intuitive understanding of mathematical ideas. For instance, in geometry, GANs can be trained on datasets containing basic shapes, spatial compositions, and geometric transformations. Once trained, they can generate new images that combine or modify these elements, offering students varied and engaging visual examples of concepts such as symmetry, rotation, proportion, and spatial relationships. Instead of relying solely on static textbook figures, learners can explore AI-generated images that highlight geometric structures in multiple ways, fostering active discovery and pattern recognition. Similarly, in arithmetic and number sense, GANs can be used to produce visual scenarios that connect numbers to quantities or operations. For example, a GAN could generate images illustrating groupings, equivalences, or progressions, allowing students to visualize addition or multiplication as transformations or aggregations of elements. This approach can help bridge the gap between concrete manipulation (e.g., counting objects) and abstract reasoning (understanding operations symbolically), which is a critical step in early mathematical learning. Moreover, because GANs can adapt to different datasets and stylistic constraints, they can be designed to reflect inclusive and diverse learning contexts. They can produce visual content tailored to specific cognitive needs, using more apparent contrasts, simplified shapes, or contextually meaningful images, thereby supporting students with special educational needs (BES) or different learning styles.

2.3 Methodology

The research design adopts a quasi-experimental research design. This methodological choice is rigorously justified by the inherent necessity of operating within an ecologically valid and non-artificial context, characteristic of real-world scholastic environments. The study employs a single-group repeated measures design articulated through the following procedural phases:

- Initial assessment (pre-test): the first step involves the administration of a set of standardised and validated instruments. These measurements are used to establish the baseline of the study group's logico-mathematical competencies, with a specific emphasis on the conceptual understanding of fundamental entities such as the cardinal number, the geometric point, and line representation.
- Intervention phase: this phase entails the implementation of the didactic program. The intervention consists of delivering the standard curricular mathematics content systematically integrated with AI-based resources, specifically focused on providing learning environments for dynamic conceptual visualisation and manipulation.
- Final assessment (post-test): upon conclusion of the pre-defined intervention period, the same (or equivalent forms of the) evaluation instruments are re-administered to measure the level of competency attained.

The subsequent data analysis focuses on quantifying the intra-group change using statistical methods appropriate for repeated measures. The research is conducted within a third-grade primary school class located in the Apulia region, Italy. The selection of this specific educational level is strategic and deliberate, as the third grade coincides with the developmental phase during which the formal introduction and in-depth study of fundamental geometric and numerical concepts take place. These concepts—such as the notion of point, line, and the structure of the number system—represent a crucial inflection point toward mathematical abstraction and are often perceived by pupils as particularly challenging. The study sample is composed of approximately 20 students from the selected third-grade class. A distinctive and crucial element of this study is the intentional inclusion of students with Special Educational Needs (BES) within this single sample group. This inclusion is not a mere statistical detail; it represents a fundamental methodological choice and a strength of the adopted design. Specifically, the intent is to verify and quantify how the adaptive functionalities, interactive visualisations, and personalised support made possible by AI systems can effectively serve as compensatory and dispensatory tools. This is aimed at enhancing access to more abstract mathematical content and actively promoting educational equity for all students, particularly those who face significant barriers to learning. One of the key challenges in mathematics education, particularly at the primary school level, is helping students build an intuitive understanding of fundamental geometric and arithmetic concepts. Children often struggle to connect abstract definitions, such as "a point has no dimension" or "a line extends infinitely," to perceptible, meaningful representations. Generative Adversarial Networks (GANs) can play a transformative role in bridging this gap by creating dynamic, contextually rich visualizations that embody these abstract notions. In the field of geometry, for instance, GANs can be trained to generate progressive visual representations that guide learners from simple to complex spatial ideas. At the most elementary level, a GAN could generate variations of points placed in different contexts (on a plane, in clusters, or along curves), helping students perceive the point not merely as a dot, but as a fundamental element from which all geometric structures originate. By manipulating attributes such as position, density, or color, learners can explore how multiple points form lines, how lines define polygons, and how these, in turn, give rise to three-dimensional shapes. Through this generative process, the model becomes a tool for constructing geometry visually, supporting the gradual abstraction process typical of early mathematical reasoning. Instead of memorizing definitions, students can "see" geometry in action: how the reflection of a triangle across an axis preserves its structure, or how changing proportions affects the perception of balance and similarity. Similarly, in arithmetic, generative models can visualize numerical relations through intuitive images. A GAN might produce visual sequences illustrating the concept of equivalence or commutativity, showing, for instance, how different groupings of objects can represent the same total quantity. By linking numbers to patterns and transformations, students begin to perceive arithmetic as a visual and structural language, not just a symbolic one. In this way, GANs offer an opportunity to move beyond static textbook figures, providing adaptive and evolving visual materials that can be tailored to learners' needs. For students with special educational needs (BES), this adaptability is particularly valuable: images can be generated with simplified contrasts, clear color coding, or familiar contexts that make abstract concepts more accessible. To operationalize the use of GANs in mathematics education, the project involves a structured integration of AI-generated visual materials within regular classroom activities. The implementation is designed around three interconnected components: the technological setup, teacher training, and the educational intervention itself. During mathematics lessons, the GAN models will be employed to generate visual and interactive learning materials that illustrate key mathematical concepts, particularly those related to geometry and arithmetic. The models will be pre-trained on curated datasets containing images of geometric shapes, spatial patterns, and object groupings representing numerical operations. Once trained, the system will autonomously produce customized visual representations aligned with the topics addressed in class, for example, generating sequences of points and lines to explain geometric constructions. Teachers will be able to select or adjust the generated images in real time, ensuring that the visual content remains pedagogically appropriate and consistent with students' cognitive levels. In this sense, GANs will function not as autonomous instructors but as creative assistants, expanding the teacher's capacity to illustrate abstract concepts through adaptive, context-sensitive visual materials. A fundamental component of the project is the professional development of teachers, designed to equip them with the necessary knowledge to utilize AI tools effectively in the classroom. Training sessions will cover both technical and pedagogical aspects:

- Technical Aspect: Teachers will be introduced to the functioning of GANs, the basics of generative modelling, and the interface used to interact with the system (selection, regeneration, and contextual adaptation of images).
- Pedagogical Aspect: The focus will be on designing didactic sequences that integrate

AI-generated materials in alignment with curricular goals, and on adopting inclusive teaching strategies that leverage visual generation to support different learning profiles. The training will span approximately 5 hours in total, combining theoretical modules with hands-on workshops. By the end of the preparation phase, teachers will have developed a small repository of AI-assisted learning activities tailored to their students. The study will extend for approximately one week; therefore, it is structured as a short-cycle feasibility study. The educational intervention will concentrate on a specific mathematical concept, progressing from elementary geometry (points, lines, and symmetry) to basic arithmetic operations (addition, equivalence, and multiplication). Students will engage in guided activities where GAN-generated images are presented, discussed, and manipulated collectively under the teacher's guidance. To assess the educational impact, the intervention will include pre- and post-tests evaluating students' understanding of the targeted concepts, as well as qualitative observations of engagement and inclusivity during the activities. The comparison between traditional and AI-supported sessions will allow the identification of learning benefits specifically attributable to the integration of generative tools. Overall, this structured implementation aims to demonstrate how AI, when thoughtfully integrated into the teaching process, can enhance conceptual understanding, foster inclusion, and stimulate curiosity, thereby transforming mathematical learning into a visually grounded and exploratory experience.

3. Expected results

The integration of Generative Adversarial Networks (GANs) into early mathematics instruction is expected to yield measurable improvements in students' conceptual understanding and learning outcomes. We hypothesize that the use of dynamic, interactive visualizations generated by AI will strengthen the cognitive link between visual representations and symbolic reasoning, particularly for abstract ideas like the geometric point or numerical equivalence. Pedagogically, this AI-supported approach is anticipated to foster active learning and curiosity, transforming students into active participants in meaning construction through exploration and self-correction. Quantitatively, we predict a significant improvement in post-test scores over baseline, reflecting enhanced conceptual transfer and application, particularly in recognizing geometric relationships and numerical equivalence. Qualitatively, the generative tools are expected to increase student engagement and participation, creating a more inclusive and stimulating environment that supports diverse learning styles. Ultimately, the project aims to provide empirical evidence that AI-based generative tools can effectively bridge the gap between abstract mathematical thought and concrete understanding

4. Discussion

The findings of this pilot study, following a thorough analysis of the literature, are anticipated to provide initial, yet compelling, quantitative and qualitative evidence supporting the core hypothesis: that the integration of Generative Adversarial Networks (GANs) acts as a critical accelerator for conceptual acquisition in primary mathematics education. This technological intervention is seen as a catalyst for a paradigm shift by moving instruction from frontal teaching toward the student's autonomous construction of meaning, profoundly transforming the educational process. The teacher's role evolves significantly from a knowledge transmitter to a cognitive facilitator and designer of AI-enhanced learning environments. By supporting dynamic and manipulative visualization, AI aligns effectively with the principles of neurodidactics, prioritizing sensory-motor experience over purely symbolic paths (Bear et al., 2016). Following this analysis, the study specifically anticipates a significant improvement in students' conceptual understanding of abstract mathematical concepts, confirming the operational feasibility of GAN integration and demonstrating the AI's potential as a compensatory tool for students with Special Educational Needs (BES), thereby promoting educational equity. However, this interpretation must be rigorously framed by the study's critical limitations: the restricted geographical and cultural focus (one class in Apulia, Italy) inherently constrains the ecological validity and transferability of the conclusions, while the brief duration of the intervention precludes any rigorous evaluation of long-term learning consolidation. These constraints underscore the necessity for future longitudinal and cross-cultural studies to validate the generalizability and sustained efficacy of this transformative pedagogical model.

5. Conclusions

The rigorous design of this study strongly reinforces the hypothesis that Artificial Intelligence holds extraordinary potential to drive a systemic transformation in education. Its core capability for deep personalization, achieved through real-time data analysis and adaptive support for BES students, is crucial for creating more personalized, inclusive, and effective learning environments. Ultimately, AI emerges as an essential tool for achieving a future where access to complex concepts is a universal resource, not a privilege. However, the large-scale adoption of AI faces systemic challenges. These include the urgent need for continuous teacher upskilling to ensure pedagogically sound integration, and the ethical imperative to guarantee equitable access nationwide, thus preventing a deepening of the digital divide. The findings from this initial study, though circumscribed, establish an indispensable launching pad for future research. The immediate methodological goal is to expand the investigation to other educational levels (secondary schools) to assess AI's role in complex subjects and its fit with adolescent cognitive needs. Equally vital is interdisciplinary expansion beyond mathematics into fields requiring advanced visualization (sciences) and text analysis (humanities). Finally, future work must include long-term, longitudinal studies to analyze the impact on learning consolidation, critical thinking development, and the broader social and ethical implications of constant AI exposure. In essence, this quasi-experimental trajectory represents a crucial first step toward redefining teaching and learning processes in service of educational equity.

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