VISUAL IMPAIRMENT AND EMPATHY: THE POTENTIAL OF ASSISTIVE TECHNOLOGIES

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ABSTRACT
Assistive technologies can be considered as mediating tools which promote different ways of accessing relationships and experience. Research on mirror neurons and embodied simulation suggests an understanding of the other rooted in the body. From this perspective, the condition of visual impairment implies further exploration of this process through sensory vicariance, enhancing touch and hearing as channels of access to relationships. In line with these considerations, assistive technologies such as the 3D printer, integrated with the use of software based on artificial intelligence, could translate experience by personalizing the educational relationships through a multisensory approach.
Starting from these premises, the contribution proposes a theoretical reflection on learning environments, in which innovation supports relational contact and broadens the pathways of empathic processes.

KEYWORDS
Assistive technologies; visual impairment; vicariance.

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Giovanni Petrillo is the author of *3. The cross-modal nature of mirror neurons in relation to empathy within the framework of vicariance* and *4. The vicarious dimension of Assistive Technologies in the relationship between empathy and visual impairment.*
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1. Introduction

In the educational field, the notion of accessibility assumes scientific value when it is referred to the quality of the available mediators and to participation. Accessibility, therefore, should be understood as the design of learning environments in which tools, languages and relationships make participation possible for all learners.

From this perspective, assistive technologies represent one of the concrete forms through which accessibility becomes educational action (Aiello et al., 2014).

The international definition of assistive technology includes products and services organized into systems oriented toward the functioning and participation of the person, with an explicit reference to the need to integrate innovations capable of affecting participation and everyday experience (World Health Organization [WHO] & United Nations Children's Fund [UNICEF], 2022). This scenario assumes particular relevance in relation to visual impairment. Indeed, in the educational field, the issue could encompass the way in which the learner with blindness or low vision accesses contents, while at the same time participating in the shared construction of meanings.

Within this framework, assistive technologies such as 3D printing and software based on artificial intelligence would allow significant experiential mediation in access to content. Their relevance could promote the replacement of an exclusively visual approach with the sharing of bodily orientations and situated communicative meanings. The relationship between visual impairment and empathy therefore requires an analysis centered on the ways through which the body constructs access to the relationship. In this regard, the concept of vicariance, theorized by the French neurophysiologist Alain Berthoz, underlines the capacity to identify alternative strategies in order to achieve the same functional objective. This concept, in relation to visual impairment, could help describe the reorganization of experience (Berthoz, 2015) thus stimulating a reflection aimed at understanding learning trajectories that follow plural pathways, in which didactic action designs conditions of sensory and cognitive access consistent with the individuality of the student (Sibilio et al., 2023). In this regard, the reference to studies on mirror neurons and embodied simulation would make it possible to open a scenario on the importance of understanding the other by activating forms of resonance rooted in the body. It is precisely in this direction that the mirror mechanism has been understood as the basis of an understanding from within of the actions and emotions of others, an understanding that involves the subject in his or her sensorimotor

organization (Rizzolatti & Sinigaglia, 2019). Consistently with this observation, the most recent neuroscientific studies have broadened the field beyond visual observation alone, recognizing distributed networks involved in social cognition and in the regulation of interaction (Bonini et al., 2022). According to this framework, it is possible to suppose that in visual impairment the experience of the other is constructed through the use of vicarious senses, such as touch, hearing and proprioception (Berthoz, 2015; Ricciardi et al., 2009). The educational environment, if designed according to a multisensory logic, can transform access to contents into a relational situation, in which teacher and student share an object and an exploratory sequence oriented toward the interpretative task (Sibilio, 2017).

Starting from these reflections, assistive technologies such as 3D printing integrated with software based on artificial intelligence could be capable of converting spatial configurations into manipulable forms, facilitating the description of images.

In this perspective, empathy could be understood as the possibility of recognizing the action and perspective of the other also through alternative sensory channels. Based on these premises, the aim of the present contribution is to suggest a possible reflection concerning the vicarious role of assistive technologies in the construction of accessible and relationally meaningful educational environments.

Through the enhancement of vicarious senses, such technologies could expand the ways in which the experience of the other is accessed, encouraging flexible and inclusive educational practices.

2. Mirror Neurons and Visual Impairment

Mirror neurons are neurons that discharge both when an individual performs a goal-directed action and when he or she perceives a similar action performed by another agent (Rizzolatti & Craighero, 2004). They were first described in the ventral premotor cortex of macaques through single-cell neurophysiological recordings and were later investigated in humans through neuroimaging, transcranial magnetic stimulation, electroencephalographic and behavioural paradigms. Subsequently, mirror neurons studies have progressively shifted the attention from the visual observation of movement to the broader relationship between perception, action and intention. For this reason, the mirror system can be considered a useful starting point for discussing non-visual access to the meaning of action (Rizzolatti & Sinigaglia, 2010).

The understanding of another person's action, on the neurocognitive level, has been investigated starting from the observation of gesture, with a progressive extension of the mirror system toward forms of coding broader than visual

coding. Rizzolatti himself, in 2004 with Craighero, defined the mirror-neuron system as a mechanism capable of linking the execution and perception of action (Rizzolatti & Craighero, 2004). This means attributing to motor representation a central role in imitation and intentional understanding. In line with this, in the perspective of embodied simulation, the subject's body constitutes the basis through which the observed action is internally modeled, with an involvement of the motor system that makes the other understandable even before an explicit inference (Gallese, 2005). On this theme, still under development today, imitation and mirror mechanisms have been connected in the field of empathy, showing that motor resonance could support processes of interpersonal recognition, especially in situations in which the gesture of the other becomes socially significant information (Iacoboni, 2009).

It has also been clarified that the action of the other is interpreted through bodily knowledge and schemes of interaction with the world, configuring a simulation that depends on the structure of the subject's motor experience (Grafton, 2009).

At this point, it is important to consider that the action of the other is not perceived only through its visible form. For example, the sound produced by an action, the rhythm of movement and the spatial organization of the interaction can also function as cues through which the subject anticipates the goal of the gesture and reconstructs its intentional structure. Many studies on auditory action representation have shown that hearing the sound of an action may activate motor representations connected to that action, suggesting that the mirror mechanism should be understood within a multimodal architecture rather than within a strictly visual model (Kohler et al., 2002; Gazzola et al., 2006). This aspect is particularly relevant for visual impairment, because it allows auditory and haptic experience to be considered not as secondary substitutes, but as alternative routes for accessing the meaning of action. But how does this social access occur in people with blindness or low vision? A first answer is provided by the fMRI study by Ricciardi and colleagues, which showed that congenitally blind people, during the auditory presentation of actions, activate areas of the mirror system, thus confirming that sight constitutes a privileged pathway, but still alongside other channels for the development and functioning of the circuits of action understanding (Ricciardi et al., 2009). This hypothesis was then confirmed by the meta-analysis by Arioli, Ricciardi and Cattaneo on social cognition in the blind brain. It further indicated, indeed, that the representation of self and others involves reorganized brain networks, with the participation of occipital areas in social and cognitive tasks of a nature different from vision (Arioli et al., 2021). Therefore, the brain could be conceived as a structure organized for operations and tasks, rather than for rigidly separate sensory modalities (Pascual-Leone & Hamilton, 2001). Visual

impairment thus highlights the possibility that a cognitive function may be supported by different perceptual inputs. This, however, provided that the environment offers stable conditions of experience (Merabet & Pascual-Leone, 2010). The educational relevance of these findings predominantly lies in designing stable sensory conditions in which action, space and intention can be explored through the body.

In other words, within a classroom, 3D printing would make it possible to transform a posture, a spatial scene or an iconic configuration into a manipulable artifact. Consequently, tactile exploration, guided by an accurate verbal description, could make available an action structure otherwise entrusted to the image. Consider, for example, a three-dimensional model of a face, of a bodily position or of a spatial sequence: these are all occasions in which a sensorimotor basis could be offered, on which the teacher builds orientation and comparison. In practical terms, the learner with visual impairment would have the possibility of following the profile of the form, as well as of locating the relationships and connecting the verbal and auditory description to the manipulated structure. Through this type of activity, the gesture of the other would depend directly on a bodily and auditory experience. Assistive technologies would mediate this experience, establishing a connection between the object and the intention of the action. Naturally, their effectiveness depends in particular on the precision of the didactic design, on the quality of the materials and on the educational relationship. This interpretation is supported by research on tactile graphics and 3D printing in inclusive and special education, which shows that printed models can facilitate access to spatial information when their design considers haptic readability, progressive exploration, guided description and the actual practices of teachers and learners (Buehler et al., 2014; Holloway et al., 2018; Di Tore et al., 2021).

It is appropriate, however, to remember that human verification remains central. It is true that such technologies can support the deconstruction of content and make it accessible. But it is equally true that the transformation into educational experience requires competence and continuous updating. Designing this kind of material means understanding which aspects of the form to make perceptible and which relationships between the parts to make stable. In didactic terms, this means that the teacher's task is to transform a neuroscientific model into situated mediations, in line with vicarious and simplex didactics, which interpret teaching as a flexible action capable of identifying alternative pathways for access, participation and meaning construction (Sibilio, 2017; Di Tore et al., 2020; Aiello et al., 2023).

3. The cross-modal nature of mirror neurons in relation to empathy within the framework of vicariance

Empathy can be understood as a complex relational function, through which the subject recognizes, interprets and partly shares the internal states of the other without cancelling the distinction between self and other. It is neither a unitary emotional response nor a simple affective contagion, but rather a dynamic configuration that integrates perceptual, bodily, cognitive and regulatory processes (Davis, 1983; Decety & Jackson, 2004). In educational contexts, it supports communication and participation, showing how understanding the other passes through embodied forms of simulation and resonance.

Social relationships and the ability to decode the emotional states of others are closely related to the activity of the mirror neuron system, which is configured as a complex neurophysiological network with a profound cross-modal nature (Rizzolatti & Sinigaglia, 2010; Bonini et al., 2022). Indeed, the growing body of scientific evidence suggests that the internal simulation of actions and the empathic understanding of the other are not rigidly connected to visual input, but rather that this neural network shows the capacity to be activated and to process the meaning of gestures and actions also through acoustic and motor stimuli (Gazzola et al., 2006; Schaefer et al., 2012). This specific cross-modal property could assume significant relevance in relation to visual impairment. In this regard, in people with blindness and low vision, several studies have observed how cortical circuits are able to reorganize themselves through the activation of residual senses, in the absence of the visual channel (Ricciardi et al., 2009; Collignon et al., 2013; Arioli et al., 2021). Touch and proprioception thus participate in the construction of sensorimotor configurations through which the action of the other could become accessible even in the absence of the visual channel. Within this framework, the concept of vicariance theorized by Alain Berthoz can offer interesting suggestions, considered as the capacity of the human brain to activate flexible and alternative pathways in order to achieve the same objective, emphasizing how the organism is structured to constantly redefine its relationship with the world through a multiplicity of access routes (Berthoz, 2015). In the educational field, this principle of biological and cross-modal flexibility translates into the need to define learning environments that value differences and validate the heterogeneity of cognitive styles, through non-linear trajectories capable of activating vicarious solutions (Aiello, 2017; Sibilio, 2017; Sibilio et al., 2023).

At this point, it is necessary to distinguish perspective taking from empathy. The former refers to the cognitive and embodied ability to decentre from one's own position and to assume, transform or coordinate another person's point of view (Kessler & Thomson, 2010).

Empathy, instead, is a broader relational process that may include perspective taking but also involves affective resonance, interpretation and regulation of

the other's emotional state (Davis, 1983; Decety & Jackson, 2004). Therefore, perspective taking can support empathic understanding, but it does not coincide with empathy. In a simplex didactic perspective, training perspective taking means promoting flexible changes of reference systems and the possibility of accessing the same situation through different perceptual and cognitive routes (Kessler & Thomson, 2010; Di Tore et al., 2020). In conditions of visual impairment, this distinction becomes particularly relevant because perspective taking may be supported by bodily, auditory and haptic configurations, in which the body, the voice and tactile exploration contribute to the construction of shared representations of experience.

In this perspective, the function of the mirror neuron system would be coherent with an embodied conception of empathy, in which access to the other would depend on the possibility of internally simulating intentions and meanings through alternative perceptual modalities. Visual impairment, therefore, could be an interesting condition for observing how perspective change may emerge from the cooperation between neural plasticity, bodily experience and sensory organization, rather than from a single perceptual channel (Ricciardi et al., 2009; Arioli et al., 2021).

In this scenario, it would be relevant to underline the inclusive potential of assistive technologies. Indeed, devices such as the 3D printer, integrated with software based on artificial intelligence, would make it possible to translate exclusively visual or abstract contents into tangible and audio-described three-dimensional models, activating vicarious sensory channels capable of dialoguing coherently with the cross-modal nature of the mirror neuron system and promoting significant empathic processes (Holloway et al., 2025; Mukhiddinov & Kim, 2021; Miao & Holmes, 2023; Naayini et al., 2025).

4. The vicarious dimension of Assistive Technologies in the relationship between empathy and visual impairment

The theoretical and conceptual framework already developed around mirror neurons, embodied simulation, and sensory vicariance would make it possible to consider assistive technologies within a broader vision of the educational environment, in which the relationship takes shape through plural sensory channels and materials that make explorable what, in ordinary educational devices, is often entrusted to the simple image. In this regard, the reading of the mirror system, projected towards distributed and cultural vectors, would offer a mobile theoretical basis from which to understand how the action of others can be grasped also in its intentional structure, as well as in its visual appearance (Bonini et al., 2022). Indeed, in students with visual impairment, the understanding of gesture and posture passes through different perceptual

textures, in which voice and contact assume a specific cognitive density. Within these textures, assistive technologies such as the 3D printer and software based on artificial intelligence could become a threshold of access to the relationship, making available a tactile and auditory configuration of experience, capable of supporting the construction of shared representations (Ricciardi et al., 2009; Elshaer et al., 2025; Naayini et al., 2025).

The 3D printer, in particular, would make it possible to translate spatial configurations and bodily scenes into physical artefacts, accessible through haptic perception, offering the learner the possibility of constructing a spatial knowledge capable of becoming embodied and of moving from the active manipulation of the material to the organization of the body schema in relation to the object (Holloway et al., 2018). In line with this perspective, the production of three-dimensional models would assume significant value, since the printed object would become a relational mediator around which teacher and learner can share orientations and communicative intentions, in the formation of a possible educational scene in which learning proceeds through the coordination between haptic experience and guided speech. In this scenario, vicariance, understood as the capacity of the organism and of educational action to find functional and alternative pathways towards a specific aim, would make it possible to interpret this technological mediation as a creative reorganization of the relationship between body and cognitive environment. For this reason, models produced with 3D printing would assume value within carefully designed educational environments, in which the haptic readability of forms and the gradualness of exploration support truly situated participation. Recent experiences of applying 3D printing in educational and rehabilitative contexts indeed show that the effectiveness of innovation depends on the professional community that integrates it, on shared participation, and on the capacity to make it a stable part of inclusive activity (Di Tore et al., 2022; Bleau et al., 2025).

In the same way, software based on artificial intelligence could be used to adapt materials and generate accessible descriptions, supporting the conversion of visual content into verbal traces or tactile information. Indeed, AI, used within a pedagogical framework and with ethical responsibility, could help teachers personalize the learning experience, selecting communicative forms suited to the learner's perceptual preferences and to the ways through which he or she reconstructs meanings within the class group (Miao & Holmes, 2023; Elshaer et al., 2025). In this regard, it would be relevant to underline that recent scientific literature on the relationship between artificial intelligence and visual impairment highlights the need to orient digital tools towards autonomy and equitable participation in educational pathways, with particular attention to the quality of educational adaptation (Naayini et al., 2025). In this scenario, the

combination of 3D printing and AI-based software could be read as a vicarious mediation, capable of enhancing the plasticity of cognitive processes and the situated nature of learning (Arioli et al., 2021).

5. Conclusions and future perspectives

In light of the reflections above, assistive technologies could be considered as relational and didactic mediators. This means that they can help transform visual, spatial and social information into forms that can be explored and shared through other sensory channels. It is particularly relevant in the case of visual impairment. In that condition, access to the other and to the educational task is constructed through the coordination of body, language and interaction. For this reason, 3D printing, in particular, would make it possible to produce tactile objects capable of transforming visual contents and spatial configurations into explorable materials. In line with this, recent studies concerning the adoption of 3D printing within educational contexts for blind or visually impaired people have shown that the success of innovation depends on collaboration among professionals, on the quality of materials and on the involvement of end users (Holloway et al., 2025).

Regarding the difficulties of adoption, they mainly concern the economic cost of devices and materials, the time required to design and test tactile models, and the technical skills needed to transform visual content into accessible artifacts. For this reason, these organizational and methodological criticalities should encourage the inclusion of such technologies within a professional community capable of supporting training, co-design and continuous didactic updating (Di Tore et al., 2021; Aiello et al., 2023). The integration of assistive technology into the teaching-learning process should therefore be understood as a sequence of didactic choices. First, the teacher identifies the content, action or relational situation that is difficult to access through vision alone. Then, he or she selects which aspects must be translated into tactile, auditory or verbal form. Finally, the student's exploration will be guided and verified through dialogue. If present in the institution, a 3D printer supported by AI-based software could contribute to this process. Indeed, it could produce tactile models and accessible descriptions. However, its educational effectiveness depends on the clarity of the objective, on the readability of the material and on the continuous verification of the learner's experience. A poorly readable tactile model, or one introduced without adequate verbal mediation, may increase the exploratory load. Conversely, a model designed according to perceptual progression can support participation and foster a form of access to

the other that does not depend exclusively on the visual channel. Even before asking which device to use, it is necessary to consider which relational experience one intends to make accessible. If the didactic objective concerns the understanding of a posture, an interpersonal distance or a social scene, the tactile support should help the student construct a representation that can be explored and shared with the group. Starting from a shared use, sighted classmates can be involved in description and in the verification of interpretations. In this way, the empathic dimension may be promoted through activities in which the class group experiences different modalities of access to the same situation, with a possible impact on the ability to consider the perceptual perspective of the other (Di Tore et al., 2020). Therefore, technology should not be attributed an automatic educational value. Its inclusive potential emerges only when adequate organizational and didactic conditions are created: teachers need time for design, specific training, opportunities for collaboration and continuous feedback from the students who use the materials. Personalization, in this sense, should be understood as an iterative and situated process rather than as the mere production of differentiated materials. It requires observation of the learner's exploratory strategies, identification of the information he or she privileges, and adaptation of mediators to the student's perceptual, cognitive and communicative profile (Aiello et al., 2014; Miao & Holmes, 2023; WHO & UNICEF, 2022). In this way, assistive technologies could contribute to shifting inclusion from an individual compensatory logic to a shared educational design. The aim would not be only to protect the student with visual impairment, but to reorganize the learning environment so that the whole class can access, compare and discuss the same experience through different sensory channels. This interpretation is consistent with inclusive education and Universal Design for Learning perspectives, which highlight the need to remove barriers, provide multiple means of access and make participation a structural feature of the learning environment (Aiello et al., 2014; Aiello et al., 2023). For this reason, the design and subsequent adoption of such tools should also involve the student himself or herself, particularly in the revision of the material. His or her exploratory response can offer concrete indications on the readability of the object and on the relevance of the descriptions provided by the teacher. In this sense, the environment itself recognizes the student's perceptual competence and assumes it as part of the educational project.

Following this approach, inclusive didactics would benefit from tools that make the structure of action more accessible. Indeed, they can allow the student to

participate in the construction of meaning. It will also need that the process through which the material is designed and used should be documented, together with the product created. Finally, evaluation could include indicators relating to tactile clarity, exploratory autonomy and learner participation, avoiding measures exclusively centered on the availability of the tool.

Such an approach would make it possible to better understand which conditions make technology truly formative.

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